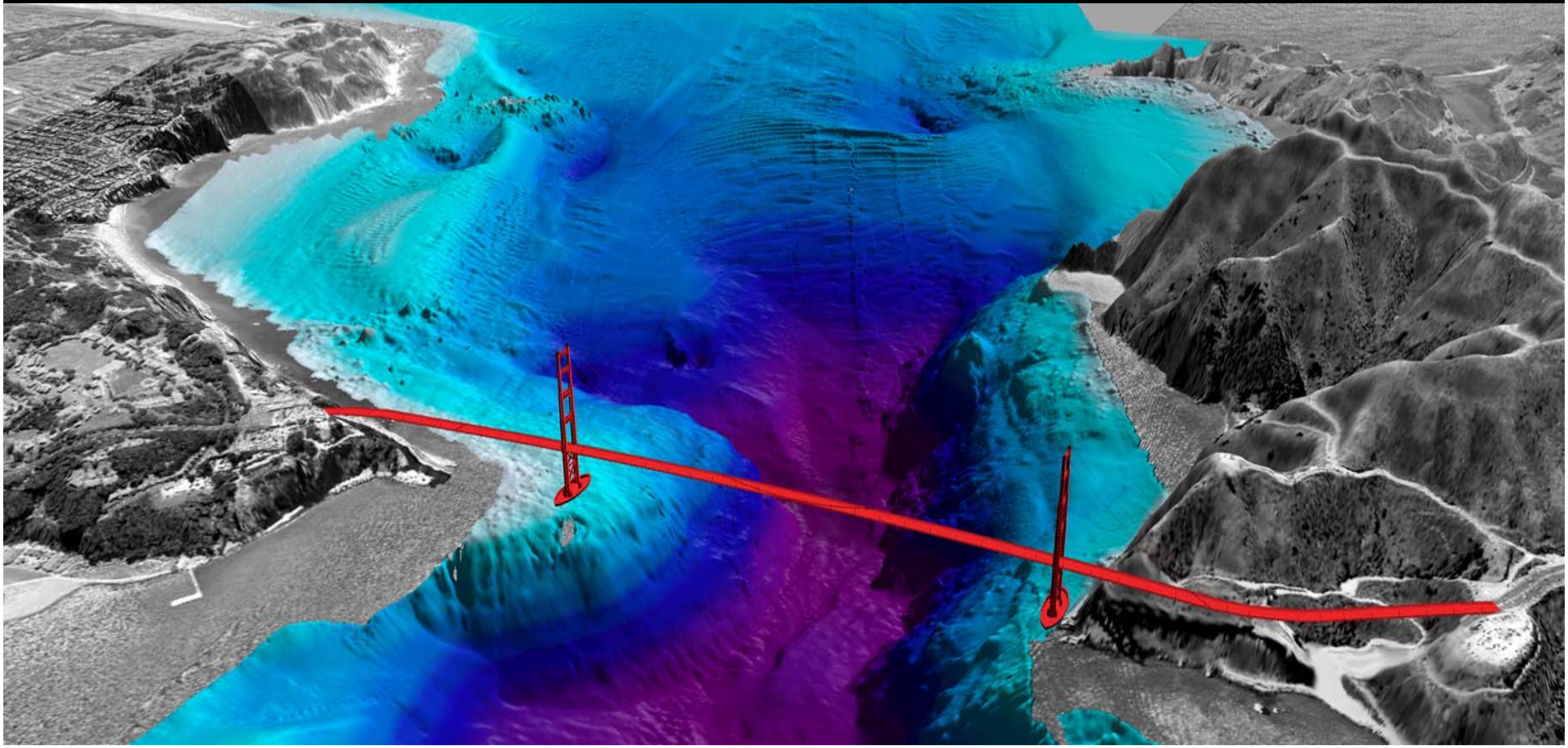
From Grain Size to Coastal Evolution: The Integration of Processes through Morphology in the San Francisco Bight

Daniel M. Hanes, Patrick L. Barnard, David M. Rubin, Peter Ruggiero, Jamie Lescinski, and Fengyan Shi



Why study O(1m) to O(1km) seabed morphology?

Eos, Transactions, American Geophysical Union, Vol. 74, No. 43, October 26, 1993, Pages 492–493.

Workshop on Geophysical Grain Flows

"Geophysical Grain Flows: Fluid-Grain Interactions in Coastal Sand Transport" was the focus of a workshop held from March 10 to 14 on Amelia Island, Fla. The workshop was sponsored by the National Science Foundation and the University of Florida. Approximately thirty-five participants from ten different countries attended, representing universities, government laboratories, and private companies.

During the workshop, one of the largest and strongest storms in the recorded history of North America impacted the eastern half of the United States. The local response of the beach at Amelia Island to this storm was striking and somewhat surprising. There was substantial accretion and widening of the beach. While the morphological changes in the beach profile were of medium to large scale, it is intriguing to realize that the changes resulted from the integrated motion of an uncountable number of sand grains, each moving more or less independently, yet cumulatively producing a wider beach.

As scientists and engineers, we are challenged to explain the dynamics of such a complex system, which consists of many components and interactive processes influenced by hydrodynamics, geology, biology, and sometimes chemistry. There are several candidate paradigms for the physical processes that caused the local accretion during the storm at Amelia Island, but there is currently no engineering model that would have correctly predicted the results. While the small-scale processes affecting the motion of individual sand grains are certainly of academic and scientific interest, and their integration in space and time leads to the large-scale changes, it is the large-scale changes that are of societal importance and therefore require engineering skill.

We are thus compelled to pose the question: should we seek to develop predictive engineering models that incorporate physical processes? If we believe the answer to be affirmative, then at what temporal and spatial scales must the physics be described if the goal is to predict medium- to large-scale coastal change? What are the natural mechanisms through which the small-scale physics are incorporated into larger-scale changes? Finally, how can we effectively mimic, in engineering models, the integration of scales that occurs in nature?

The disparity of the scales is large, and their interlinking represents a significant conceptual challenge. The small-scale processes occur roughly on spatial scales ranging from 10^{-4} to 1 m, and time scales of 10^{-1} to 10^{2} seconds, whereas the large-scale processes of great importance occur roughly on spatial scales ranging from 10^{2} to 10^{5} m and time scales ranging from 1 hour to many years. We therefore must develop an understanding of the small-scale physics that allows parameterization and its implied integration into larger-scale models.

The workshop consisted of three main activities. Individuals first gave short presentations to highlight their current research progress. Then a series of working groups and discussions resulted in identifying the general themes described previously. During the final third of the workshop, individuals meandered into small working groups to try to focus on optimal areas for research. This led to several enthusiastic discussions peppered with divergent opinions. In light of the individual biases, the working groups were able to recognize several important areas for research that should lead to significant enhancements to our current understanding and predictive capabilities.

Foremost among these recommended research areas is the need to develop an understanding of the workings of a wave-seabed boundary layer consisting of a mixture of grains and water under natural conditions. The large body of scientific literature regarding hydrodynamics overlying fixed beds is subject to considerable modification due to the influences of the moving grains. For example, the phenomenon known as "sheet flow," which may be described as a thin, dense mixture of grains and water undergoing rapid flow, changes the essential physical processes of vorticity generation and sediment entrainment at the seabed. Similarly, real world phenomenon such as boundary layer ventilation, sediment size sorting, oscillatory bursting, and the formation/interaction of bedforms all require significant level of research in order to provide a physics-based understanding of their effect upon the wave-current boundary layer and the entrainment and transport of sediment.

Experimental capabilities have recently been enhanced by more powerful computers and by instrumentation such as electro-magnetic flowmeters, acoustic concentration profilers, high-accuracy pressure transducers, rapid survey techniques, and video monitoring. These improved capabilities, as well as the development of several large laboratory facilities worldwide, provide confidence that a significant and coordinated research effort would prove highly productive. Much of the small-scale physics may be studied at prototype scale under well controlled laboratory conditions. Consequently, the development of theoretical models can be guided by realistic observations and simulations.

Finally, our "understanding" of the small-scale physics and our ability to integrate our "understanding" into larger scales should be tested in a field experiment of intermediate scale. There are many such experiments that could be carried out, but two are identified based upon the following consideration. Usual field conditions are close to equilibrium, but extreme events are far from equilibrium and therefore much more interesting and important. A similar conclusion is reached when considering the impact of coastal erosion upon the national infrastructure. Coastal property, ports, harbors, channels, and recreation areas are all adversely affected by extreme erosion events. The field experiments should therefore be designed to study unusual conditions.

The experiments should combine measurements and analysis of processes that occur on both small and intermediate scales. Either of the following experiments would provide an initial test for models that attempt to incorporate small-scale physics into large-scale coastal change. The first example is to study the response of a beach nourishment project over a time scale of a few months. The artificially placed beach would be significantly out of equilibrium, so one could expect rapid profile adjustment. The second experiment is to study the response of a natural beach system to a significant storm, including the post-storm response. There are various relative advantages and disadvantages of these two experiments; probably both should be carried out.

For more information about this workshop, contact Daniel M. Hanes, Department of Coastal and Oceanographic Engineering, University of Florida, PO Box 116590, Gainesville, FL 32611; tel. 904-392-9801; fax 904-392-3466; e-mail hanes@coed.coastal.ufl.edu.

Acknowledgments: The contributions of Anthony Bowen and James Jenkins are gratefully acknowledged.—*Daniel M. Hanes, University of Florida, Department of Coastal and Oceanographic Engineering, Gainesville, Fla.*

0096/3941/7443/93/492/$01.00.

Hanes et al., EOS, 1993:

…should we seek to develop predictive engineering models that incorporate physical processes?

…what temporal and spatial scales must the physics be described if the goal is to predict medium- to large-scale coastal change?

Today's suggestion: The gap between grain-scale processes and large scale coastal behavior is bridged in nature by a full range of intermediate scale seabed morphologies, thus providing a potential opportunity to mechanistically connect different scales.

San Francisco Bay and Coastal Region, Central California

Regional Motivations for Scientific Investigations:

- **Sediment Management**
- **Coastal Erosion**
- **Water Quality**
- **Shipping and Navigation**
- **Ecology (National Marine Sanctuary)**
- **Pollutants and accidental spills**
- **Security**

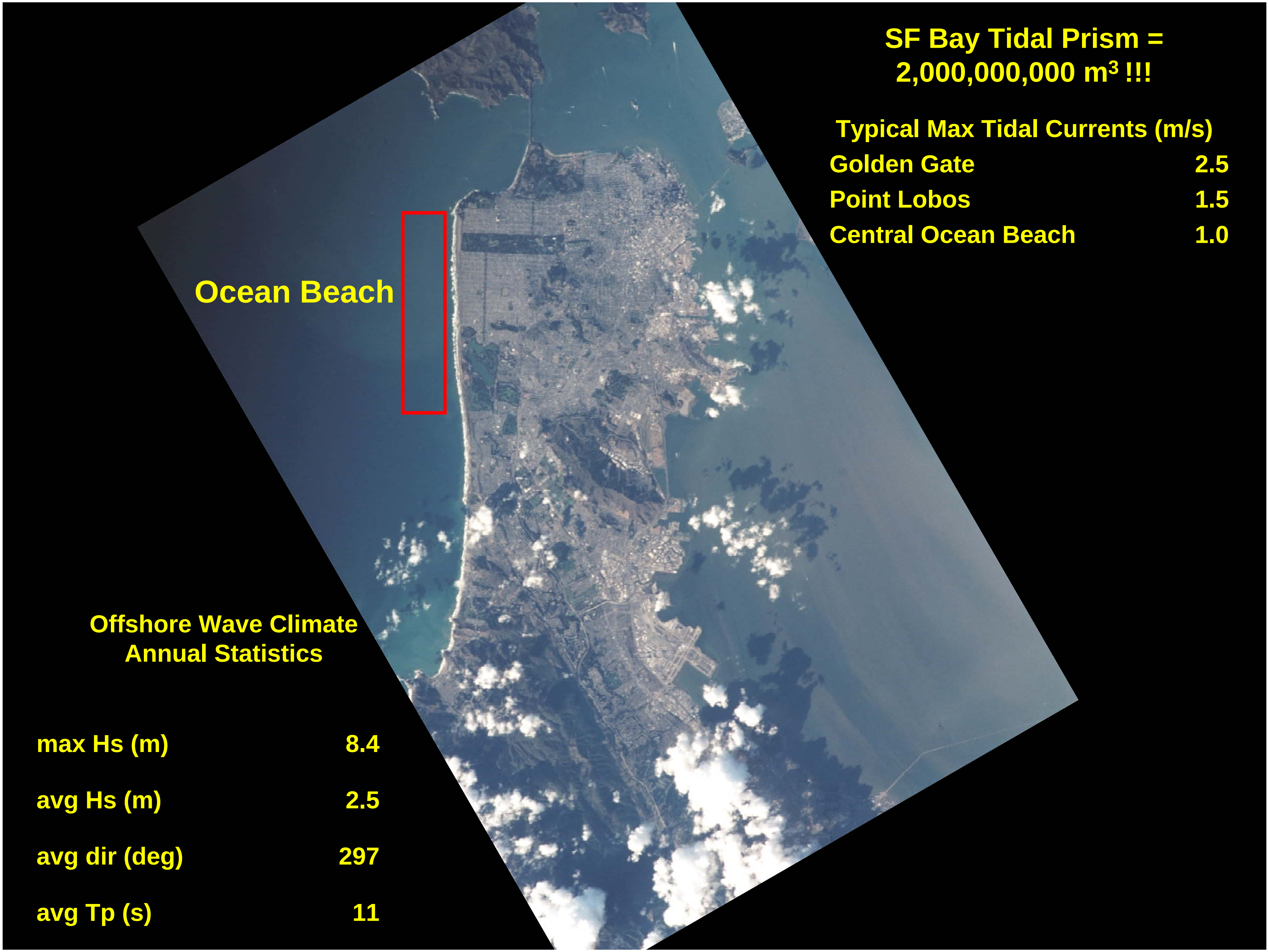
Ocean Beach Erosion- near Sloat Blvd/S.F. Zoo

1979

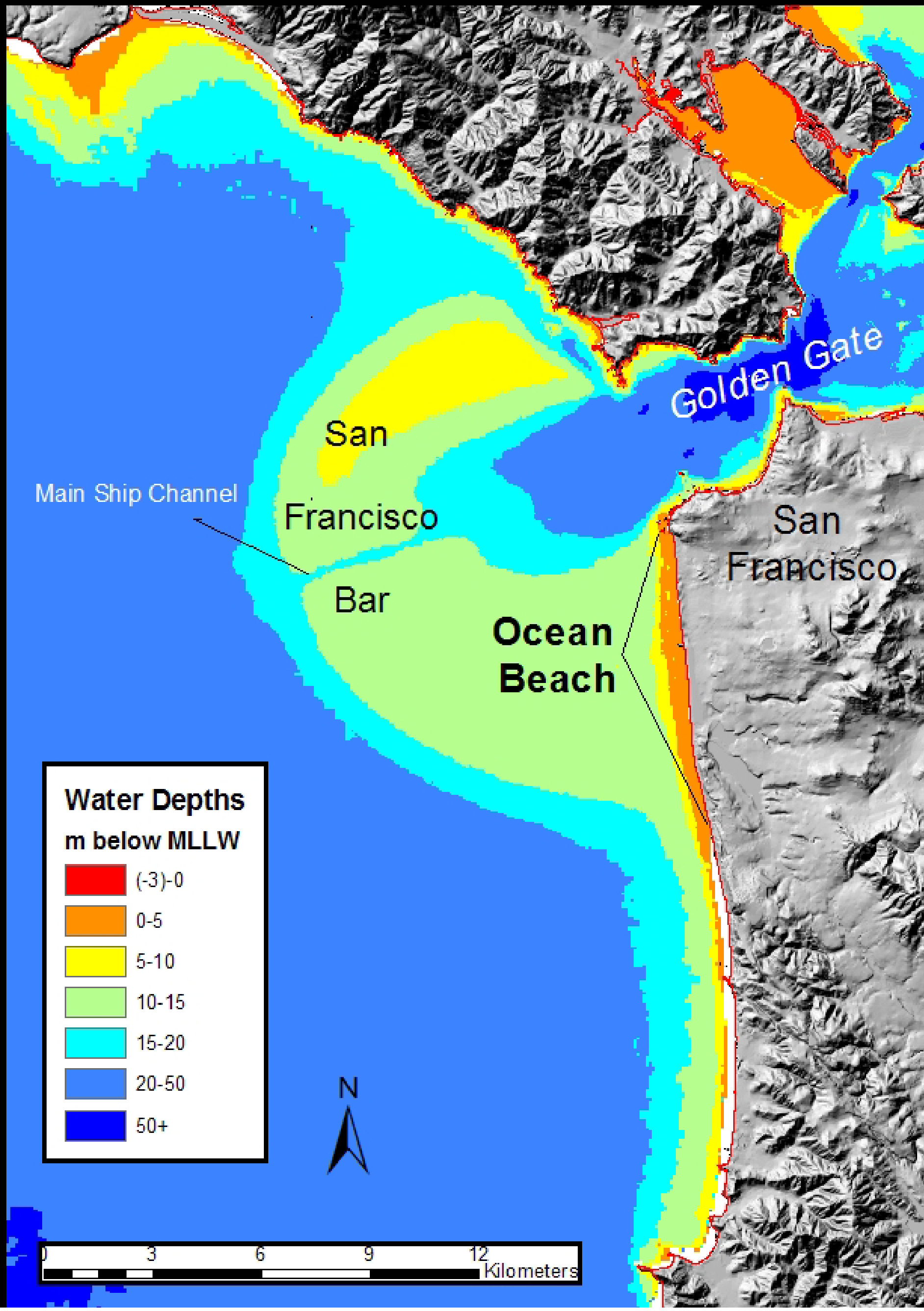
1987

1998

2003


SF Bay Tidal Prism =
2,000,000,000 m3 !!!
Typical Max Tidal Currents (m/s)
Golden Gate 2.5
Point Lobos 1.5
Central Ocean Beach 1.0
Ocean Beach
Offshore Wave Climate
Annual Statistics
max Hs (m) 8.4
avg Hs (m) 2.5
avg dir (deg) 297
avg Tp (s) 11

San Francisco Bight Coastal Processes Study



http://walrus.wr.usgs.gov/coastal_processes/intro.html

Field observations and numerical modeling designed to describe and explore the hydrodynamics, morphology, and sediment transport pathways of the region.

Last comprehensive bathymetric survey: 1956 NOAA lead-line

High resolution multi-beam bathymetric survey

Sea Floor Mapping Lab, CSU Monterey Bay, Rikk Kvitek, director

Co-funded by USGS and USACE, SF District

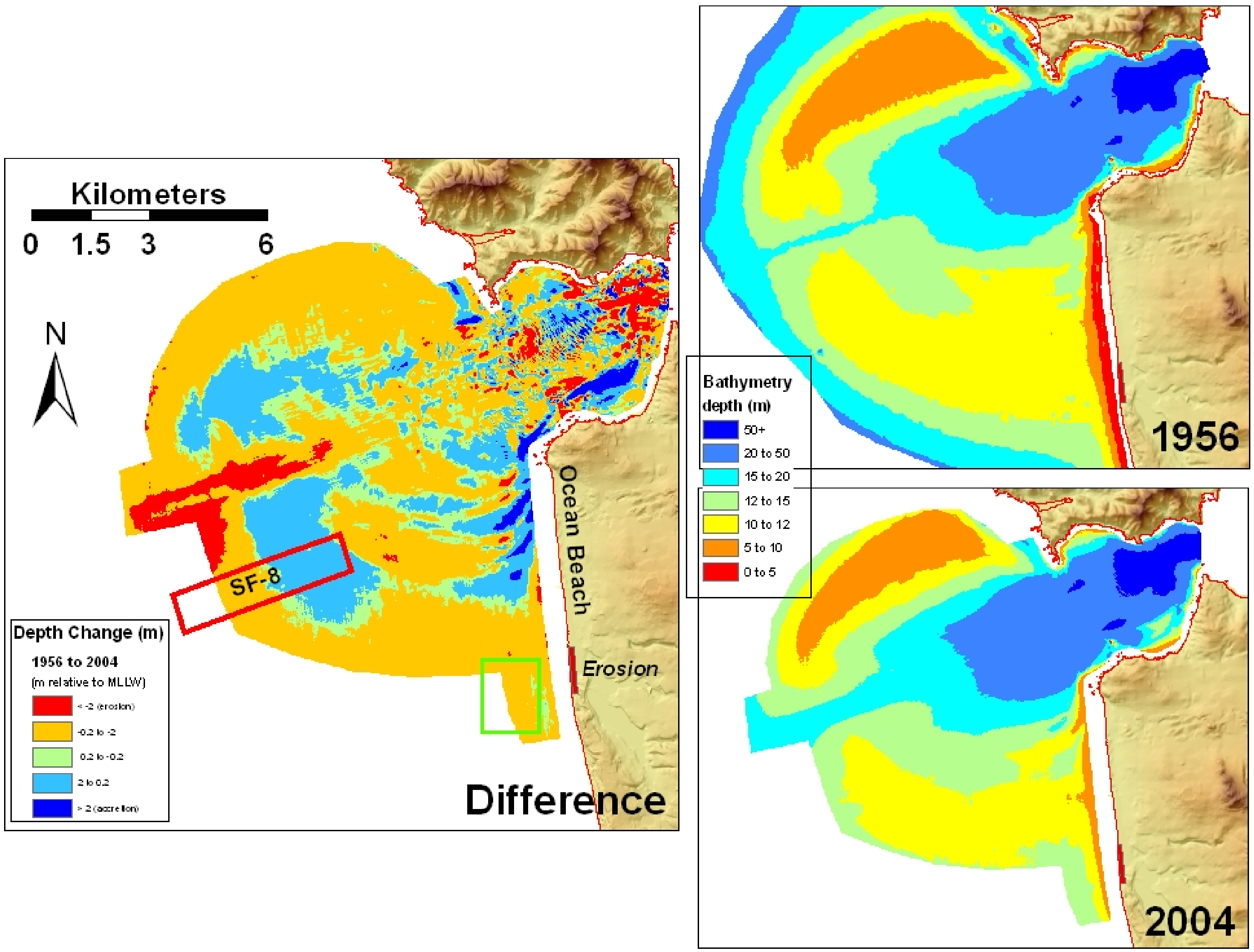
Surveys days:

35 in 2004,

15 in 2005,

15 planned for 2006

Ebb Shoal Depth Change over past 48 years



Bedform Examples from Multibeam Survey

Extremely variable bedform morphology and scale, with some very sharp boundaries;

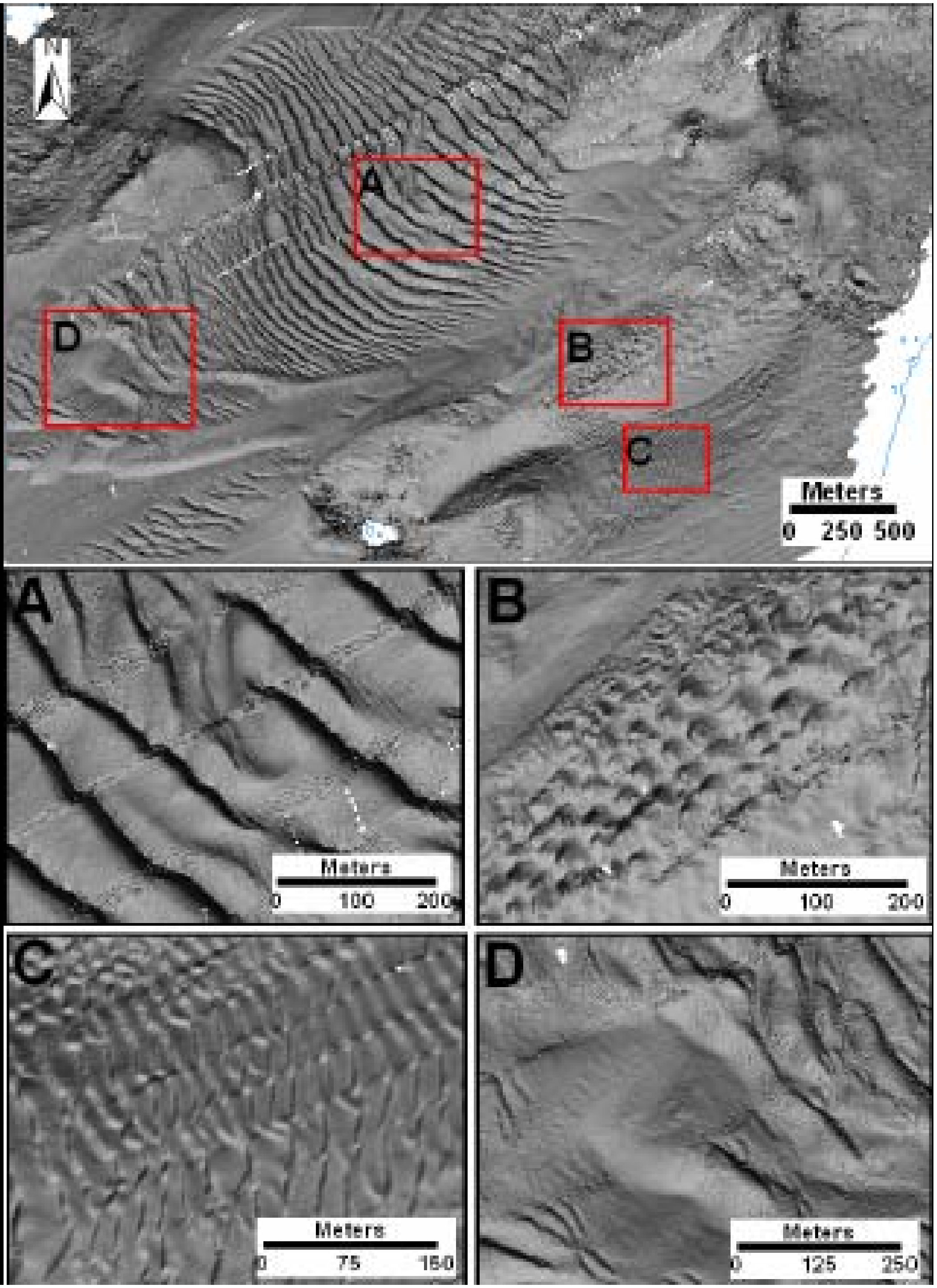
Panels:

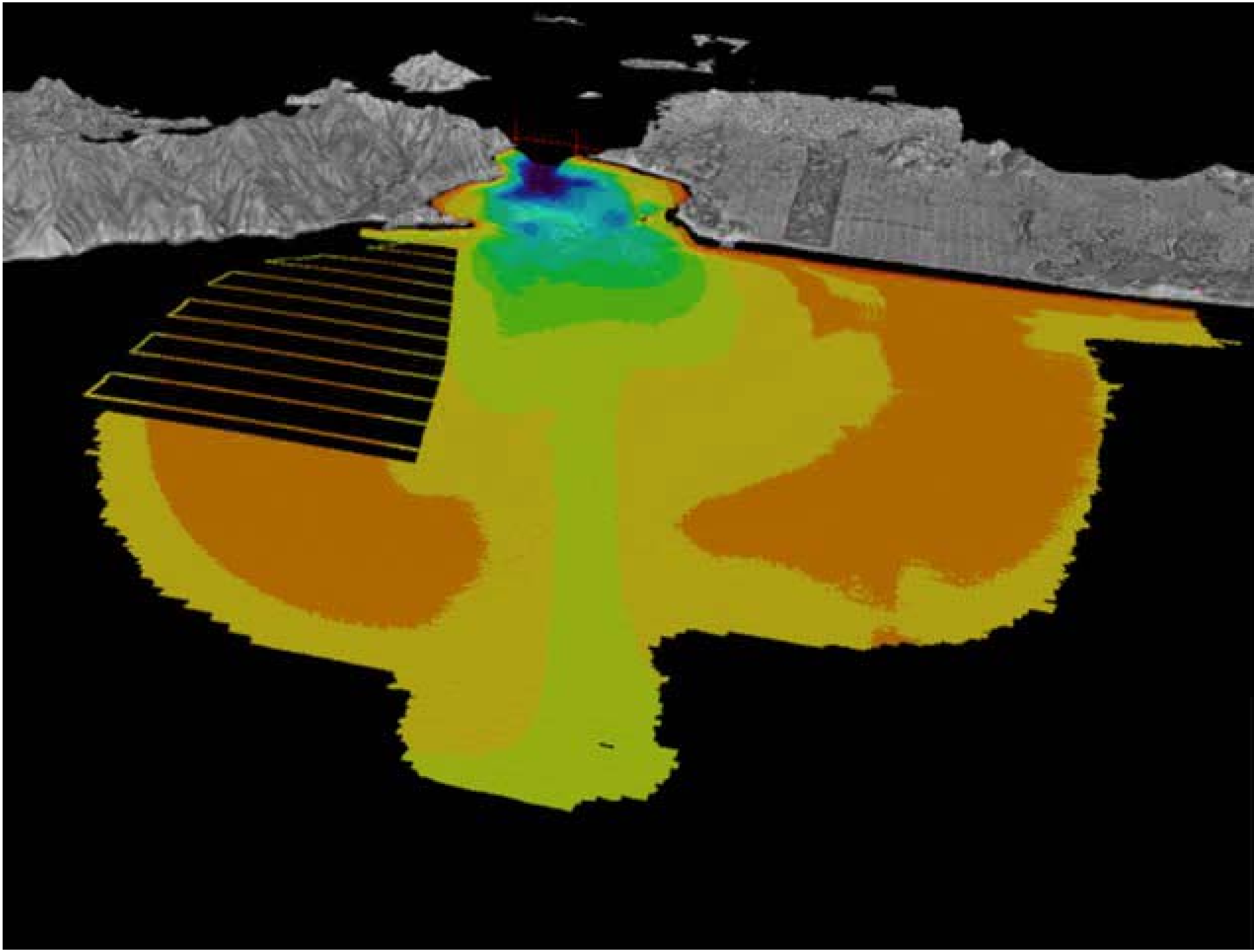
A) Giant sand wave field, up to 150 m wavelengths, nearly two dimensional, ebb dominated with superimposed 5 to 10 meter scale dunes.

B) Linguoid sand waves or very large megaripples, regular but three dimensional pattern, 20-30 m scale.

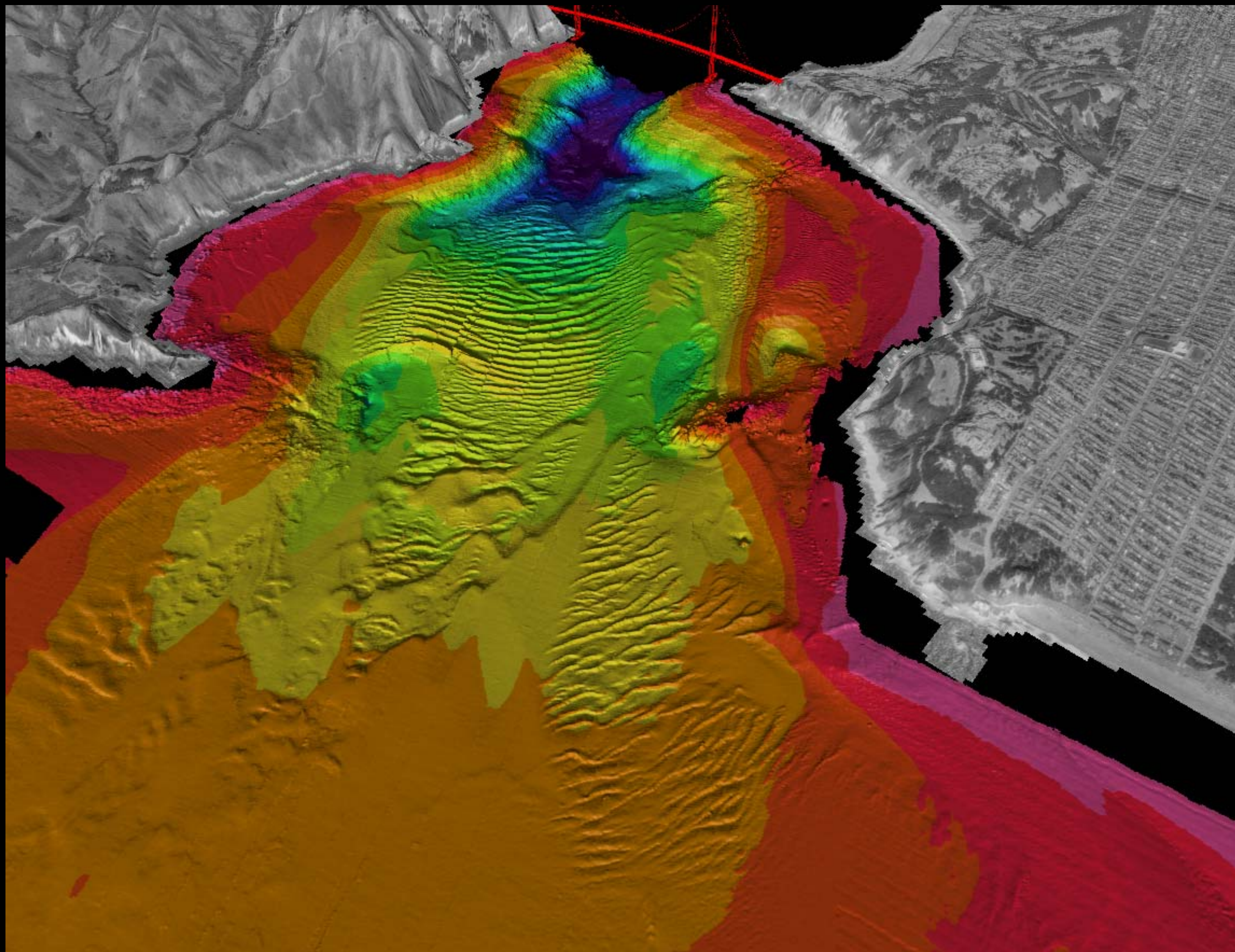
C) Sand waves, flood-dominated, 15-20 m scale.

D) Irregular, three-dimensional sand waves seaward of the main sand wave field.

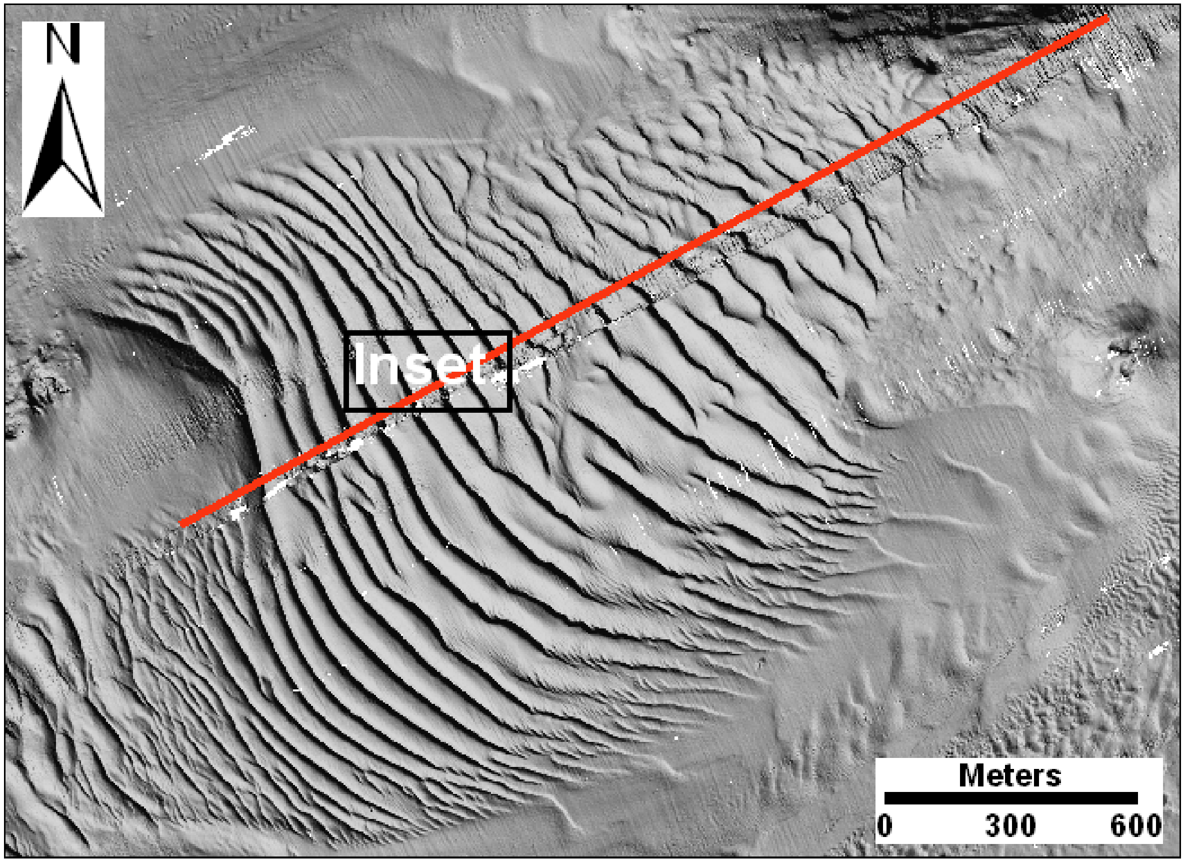


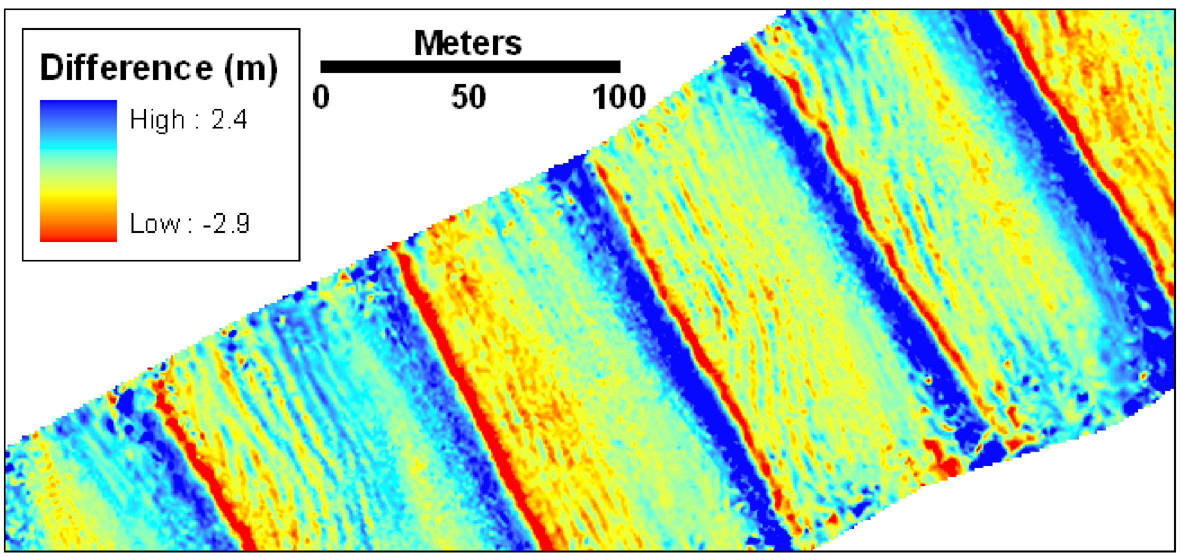


Field of Giant Sand Waves



Giant Sand Waves are Dynamic!





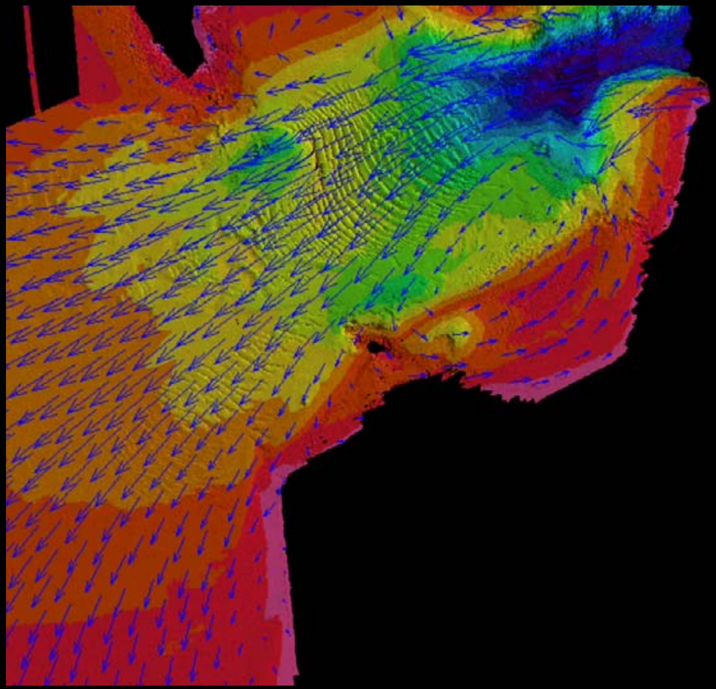
Difference between two surveys separated by 12 days

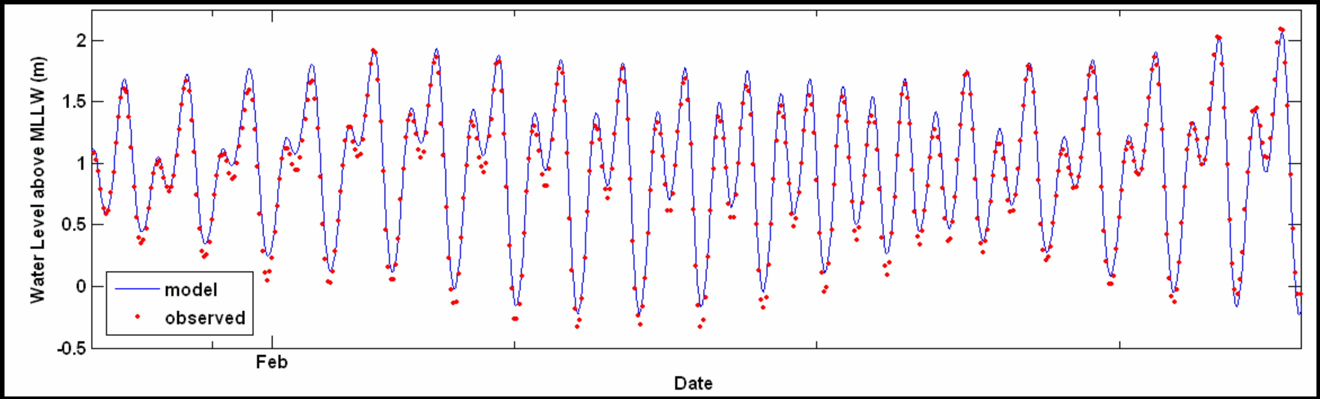
Modeling

Delft3D and NearCoM

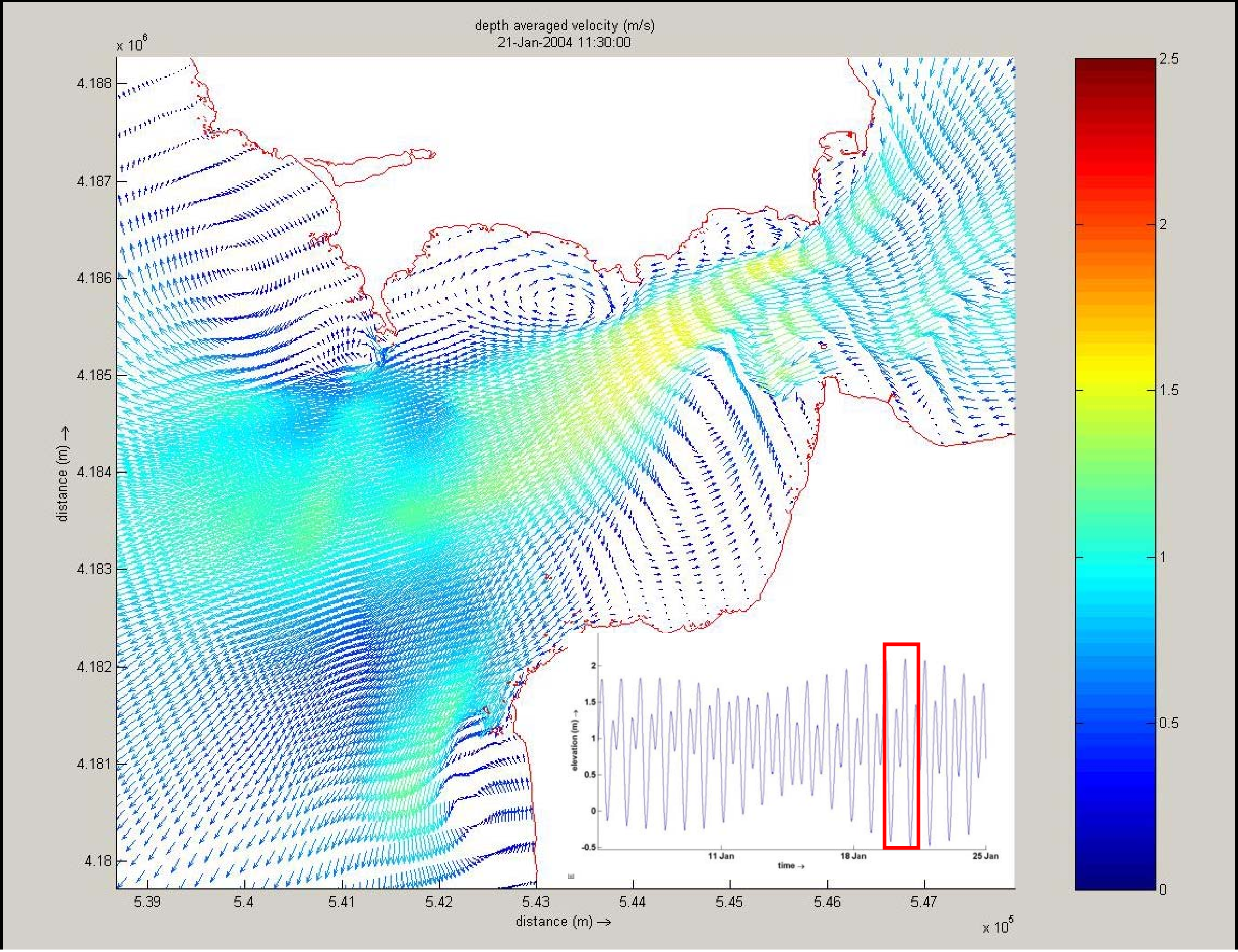
3 spatial scales: estuary, shelf, beach

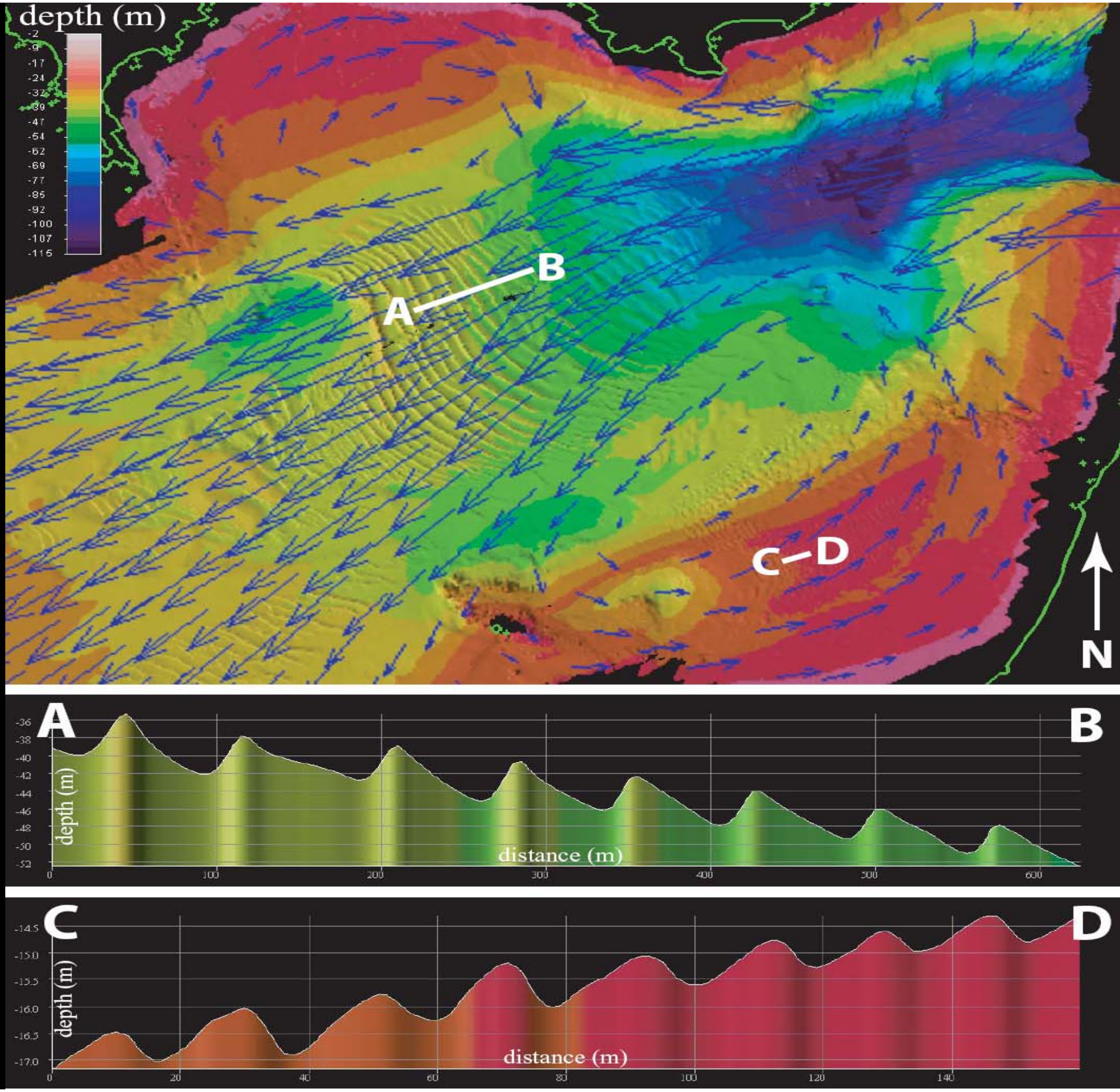
Goals: Wave evolution, circulation, sediment transport and morphological evolution on the inner shelf and in the surf zone.





Mouth of SF Bay Tidal Currents




depth (m)
-2
-9
-17
-24
-32
-39
-47
-54
-62
-69
-77
-85
-92
-100
-107
-115
A
B
C
D
N
depth (m)
distance (m)
depth (m)
distance (m)

Summary

- The SF Bight is an area of high energy waves and currents and ample sediment, resulting in an abundance and diverse variety of bedforms.
- Ocean Beach and its erosional trend are related to the larger system including SF Bay and the ebb tidal shoal.
- The entire ebb shoal has contracted over the past half century.
- Particularly interesting is a field of giant, dynamic, sand waves just outside the Golden Gate.

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Project Support and Participants

- USGS Support:
  - Mendenhall Post-doctoral Fellowship (Patrick Barnard)
  - Coastal Evolution: Process-based, Multi-scale Modeling Project (Peter Ruggiero, Jamie Lescinski, Li Erikson, Ann Gibbs, MARFAC)
  - Delft Hydraulics Cooperative (Giles Lesser)

- Academic Partners
  - Cal State Monterey Bay (R. Kvitek, Seafloor mapping lab)
  - San Francisco State (Jeff Hansen)
  - University of Delaware (Fengyan Shi)

- Collaborating Agencies:
  - U.S. Army Corps of Engineers (San Francisco District)
  - City of San Francisco
  - California Department of Boating and Waterways
  - National Park Service (Golden Gate National Recreation)

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In closing, some poetry!

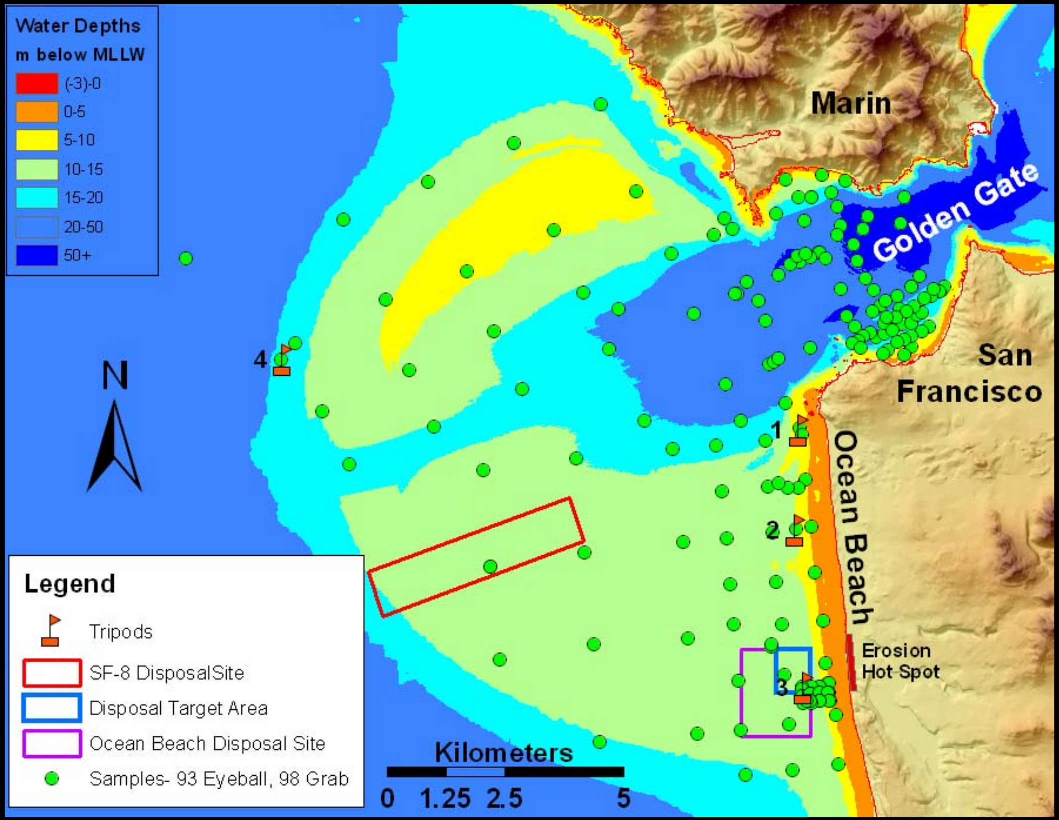
L.F. Richardson, on the cascading scales of hydrodynamics :

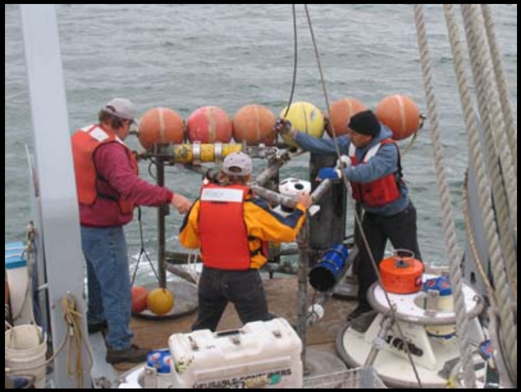
Great whirls have little whirls
That feed on their velocity
And little whirls have lesser whirls
And so on to viscosity

Is there any analog for sediment transport and/or morphology?

Grains move to and fro
Forming wiggles and bumps that grow
Into dunes, bars, and swales
Merging and bridging scales
From the grains coefficient of restitution
Up to coastal evolution

Summer 2005 Field Work

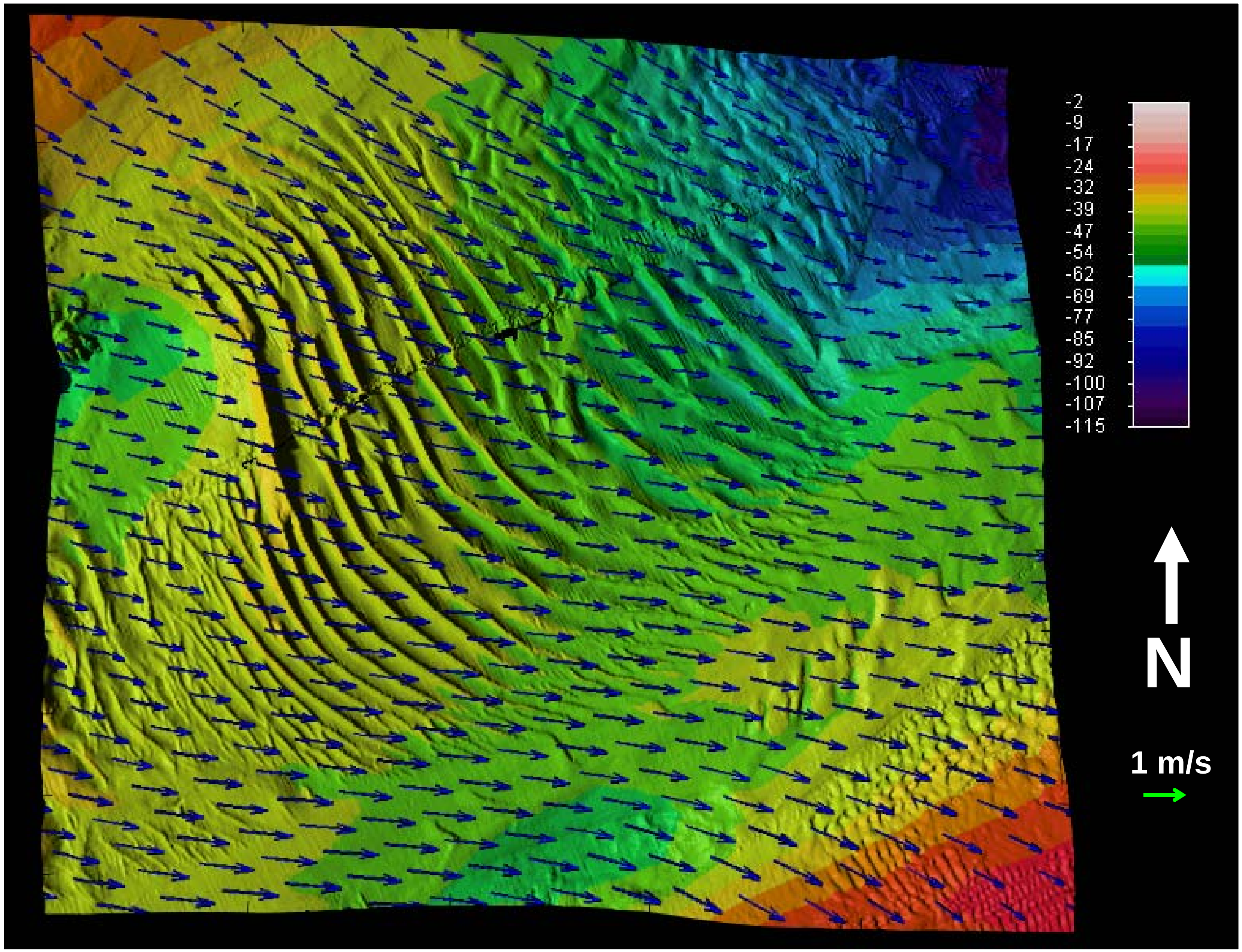




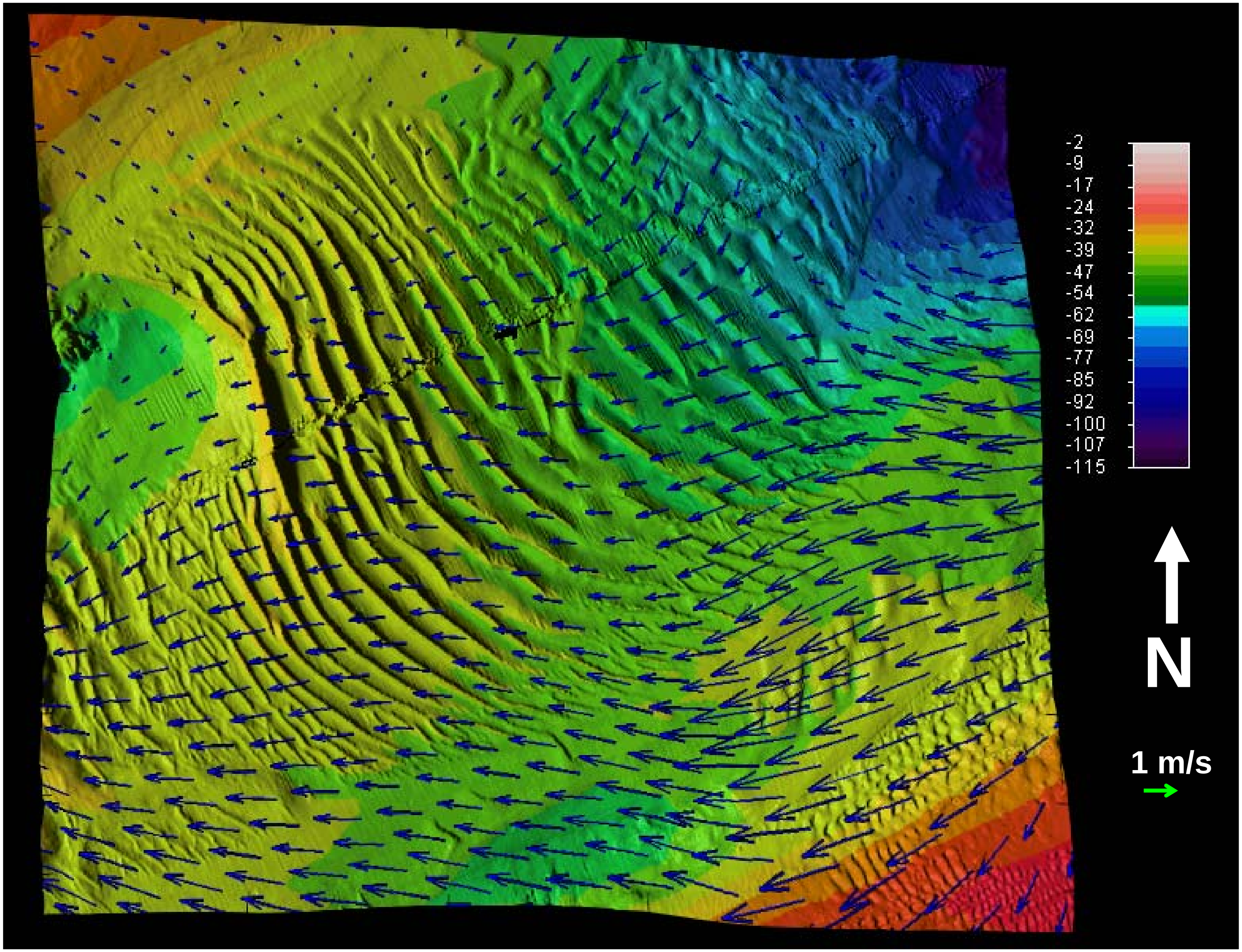
Possible causes for the erosional hot spot in the southern portion of Ocean Beach

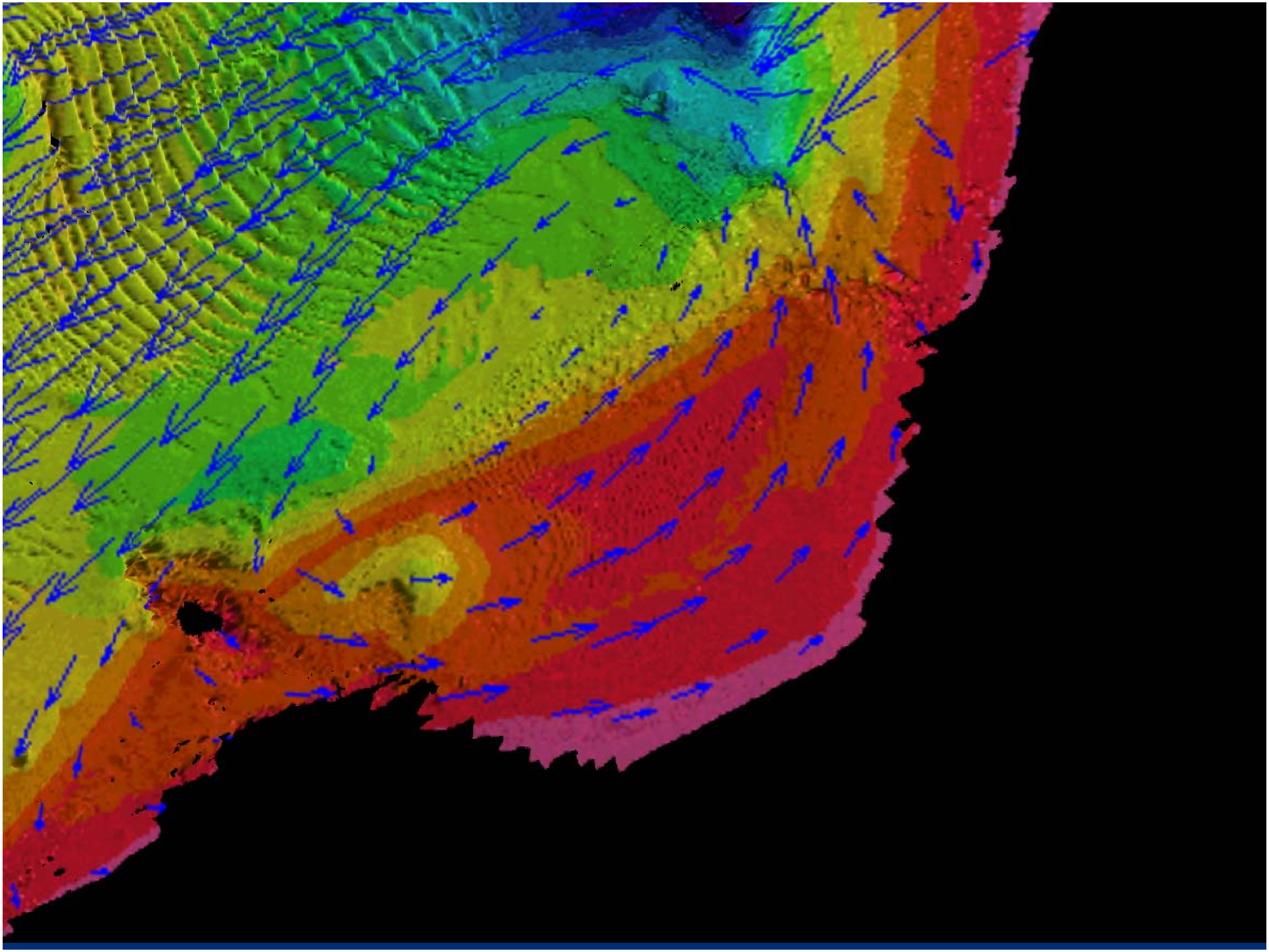
- The local wave refraction due to bathymetry results in a divergence of longshore sediment transport.
- The entire ebb tidal delta has shrunk in extent due to a reduced tidal prism- thereby altering wave refraction/focusing patterns and sediment transport pathways.
- The system is sediment starved due to extensive river damming coupled with a significant decrease in delta discharge.
- The area is a natural low spot along the coast due to tectonic processes.

Flood Flow October 22nd, 2004 1300

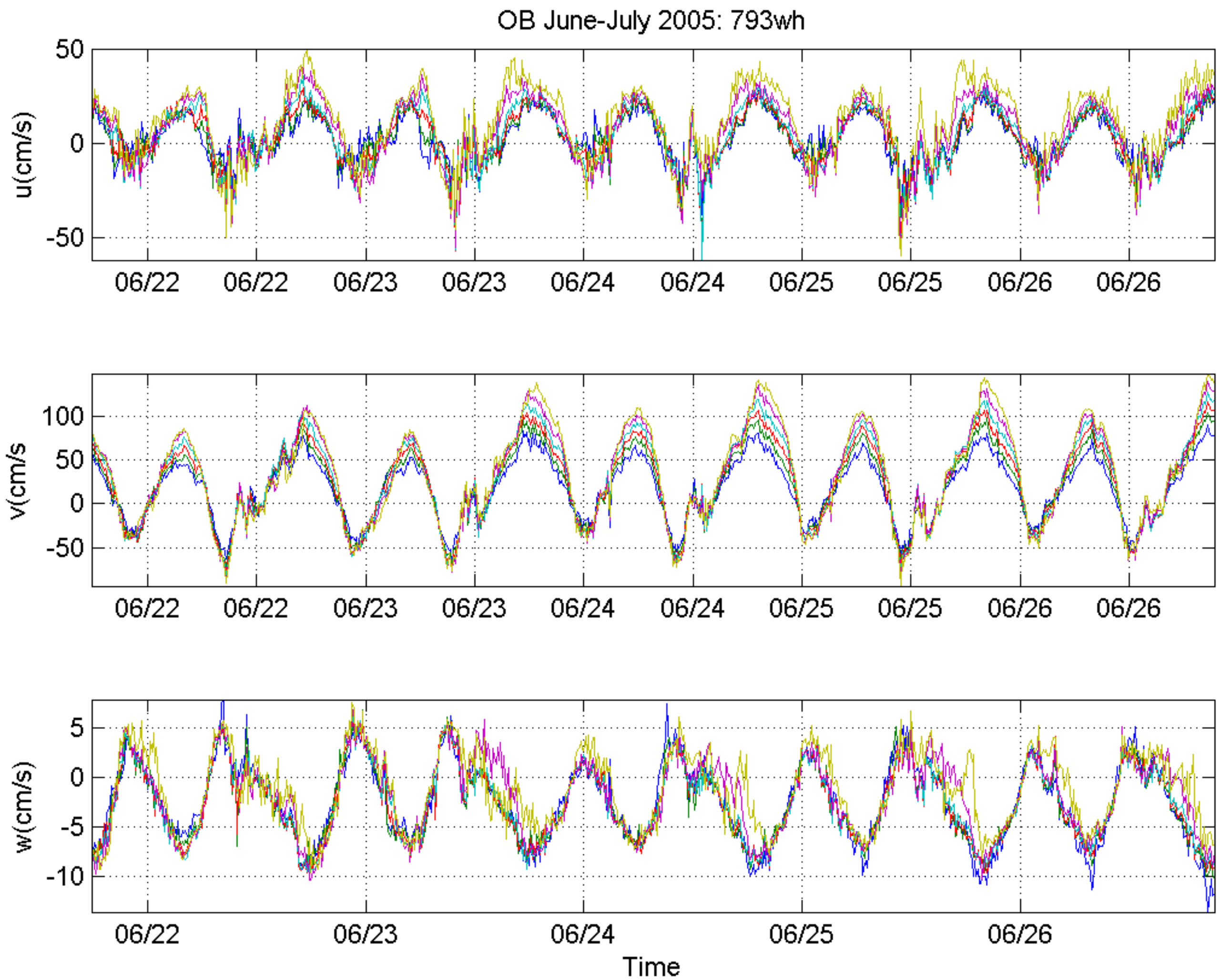


Ebb Flow October 22nd, 2004 0630

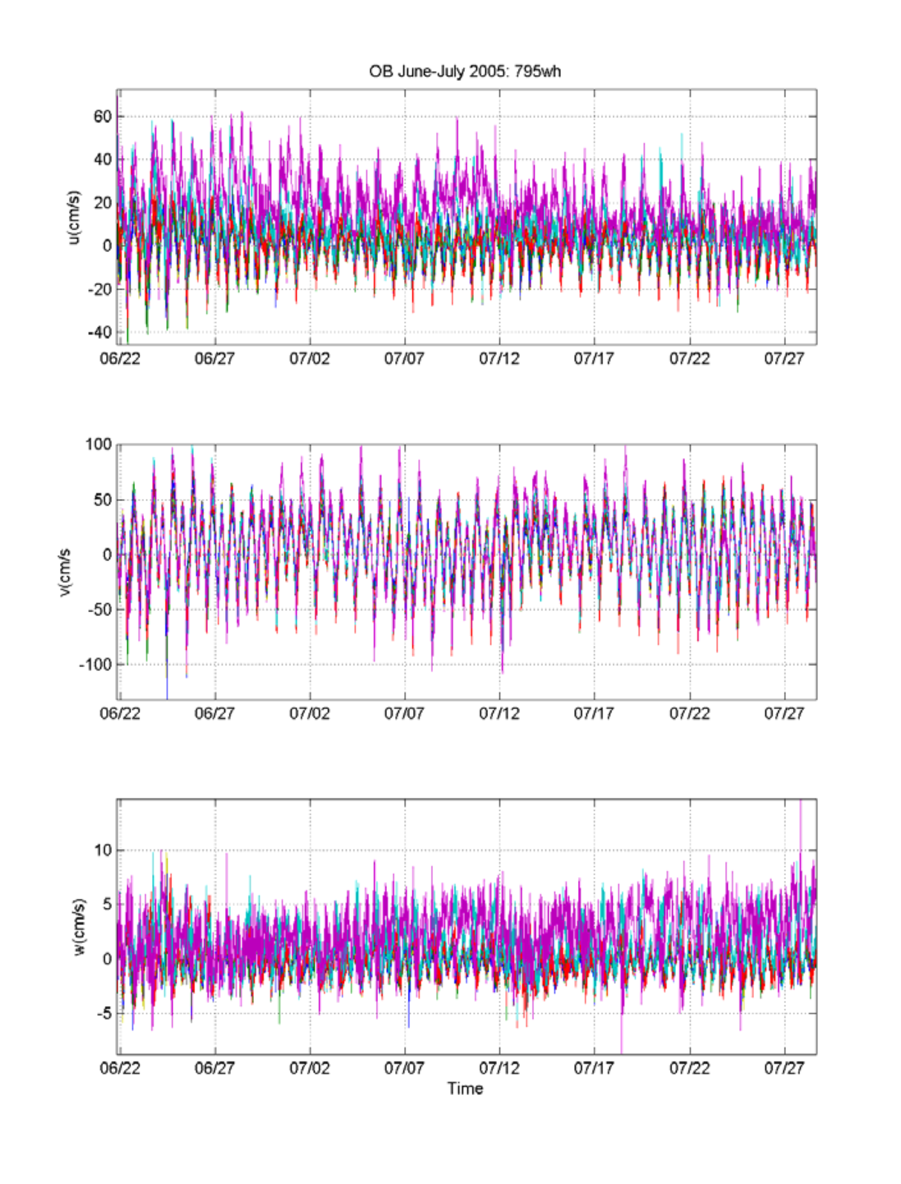


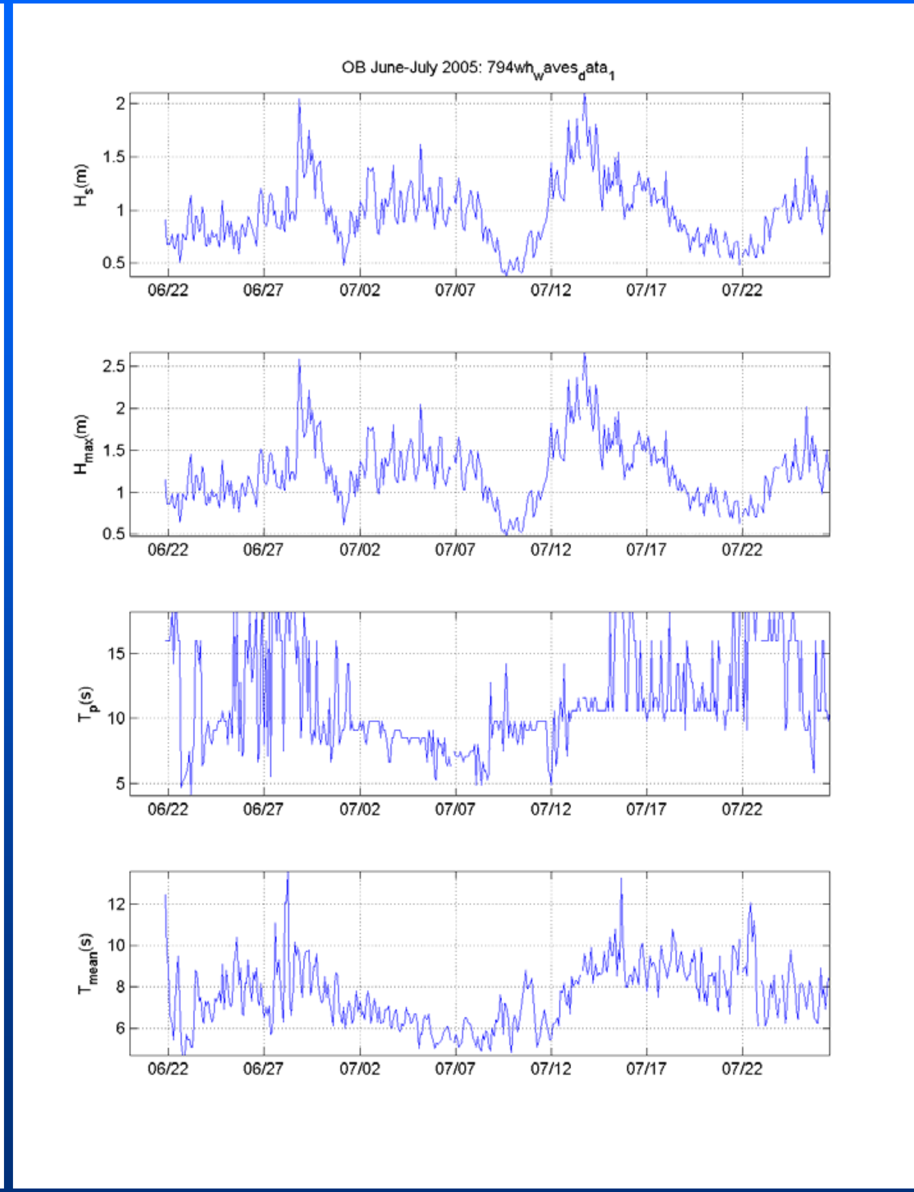


ADCP Flow Profile Time Series

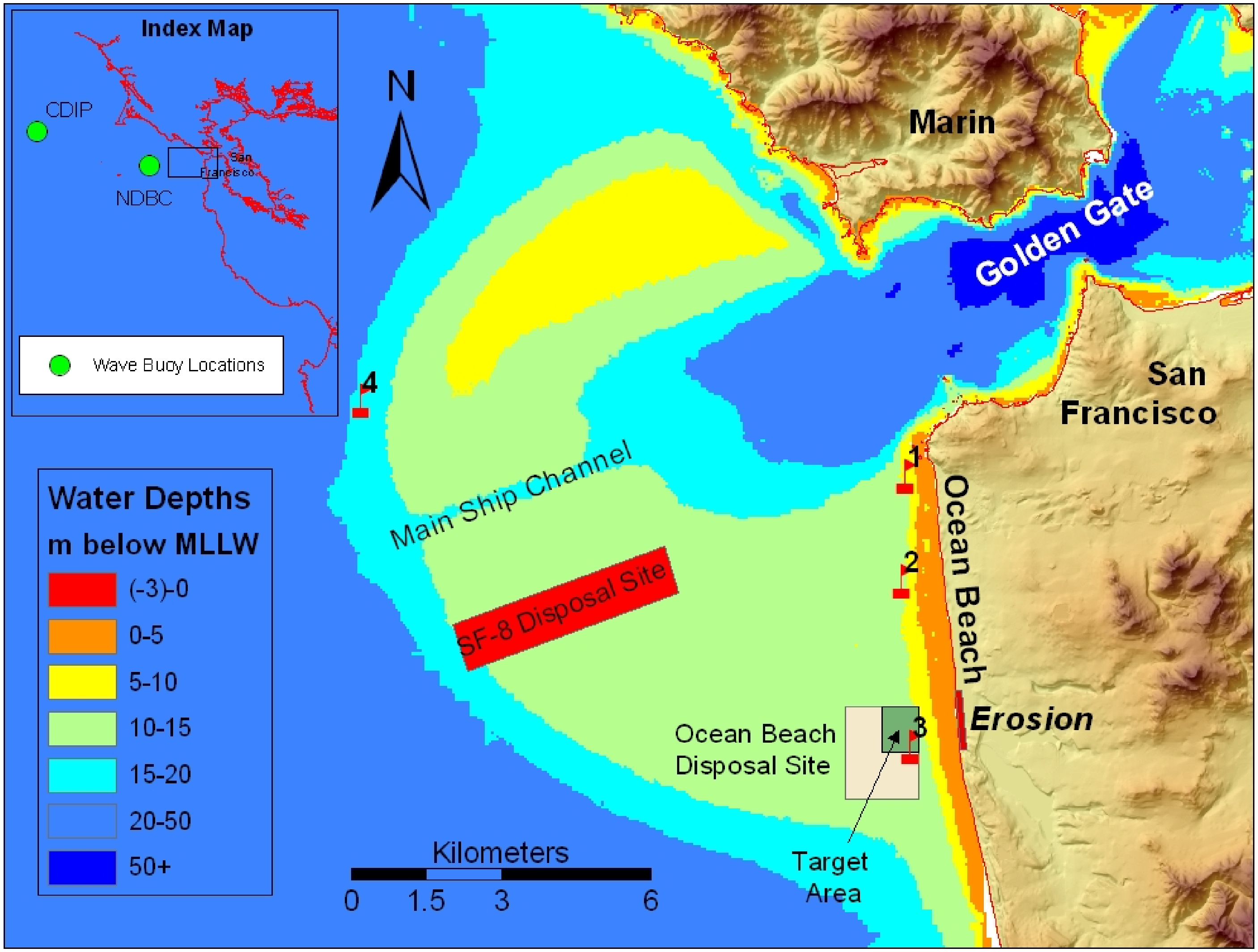


Wave and Current Measurements

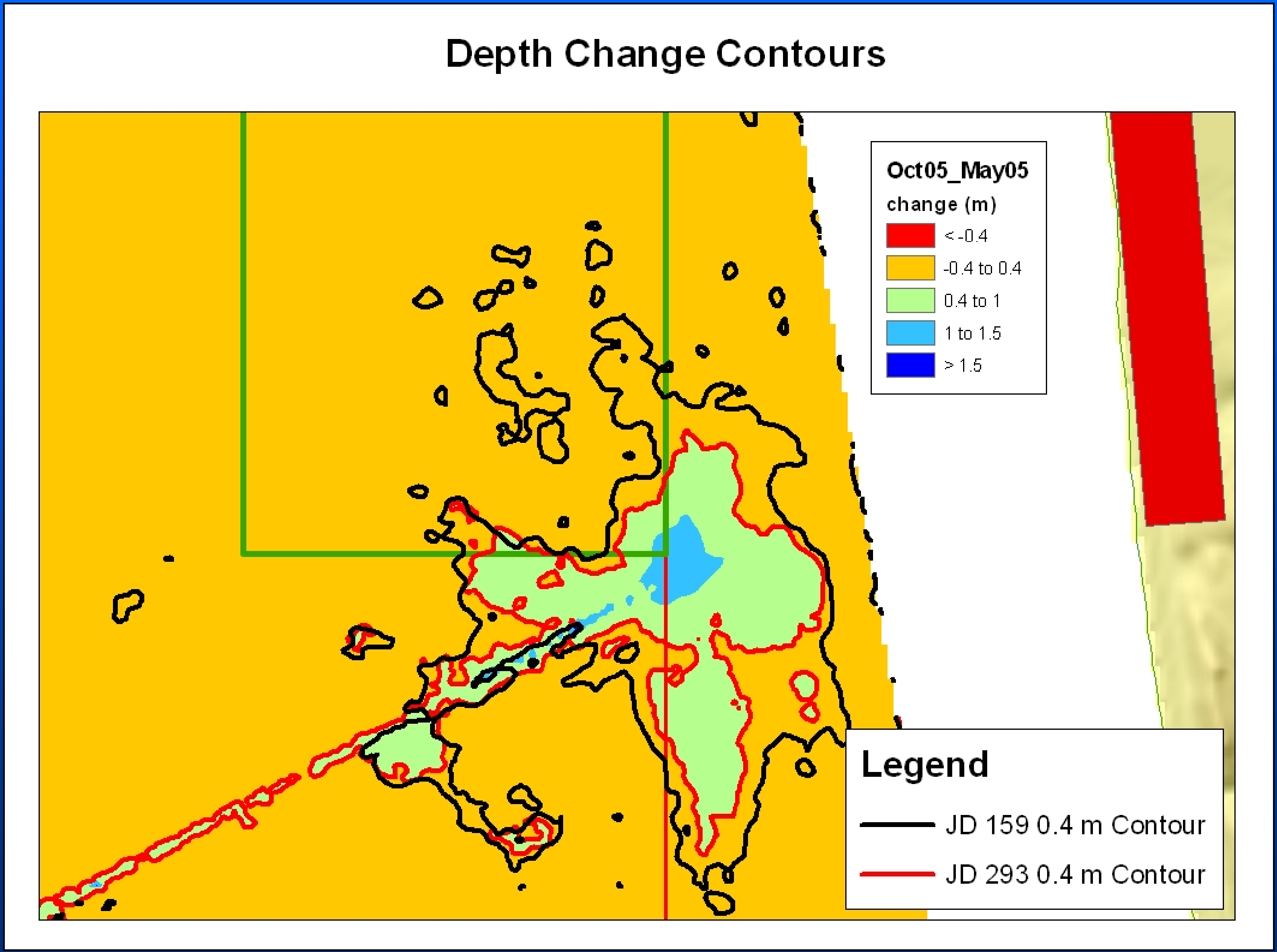




June 2005 Dredge Disposal Plan



Disposal Area



Future Directions

- Model validation with open coast in-situ measurements in key locations, including inside the surf zone
- Modeling of new dredge disposal options and shore protection concepts
- Web-based, near-real time coastal observing system
- Storm impact and risk assessment
- Winter instrument deployment for model validation
- Link to San Francisco Bay

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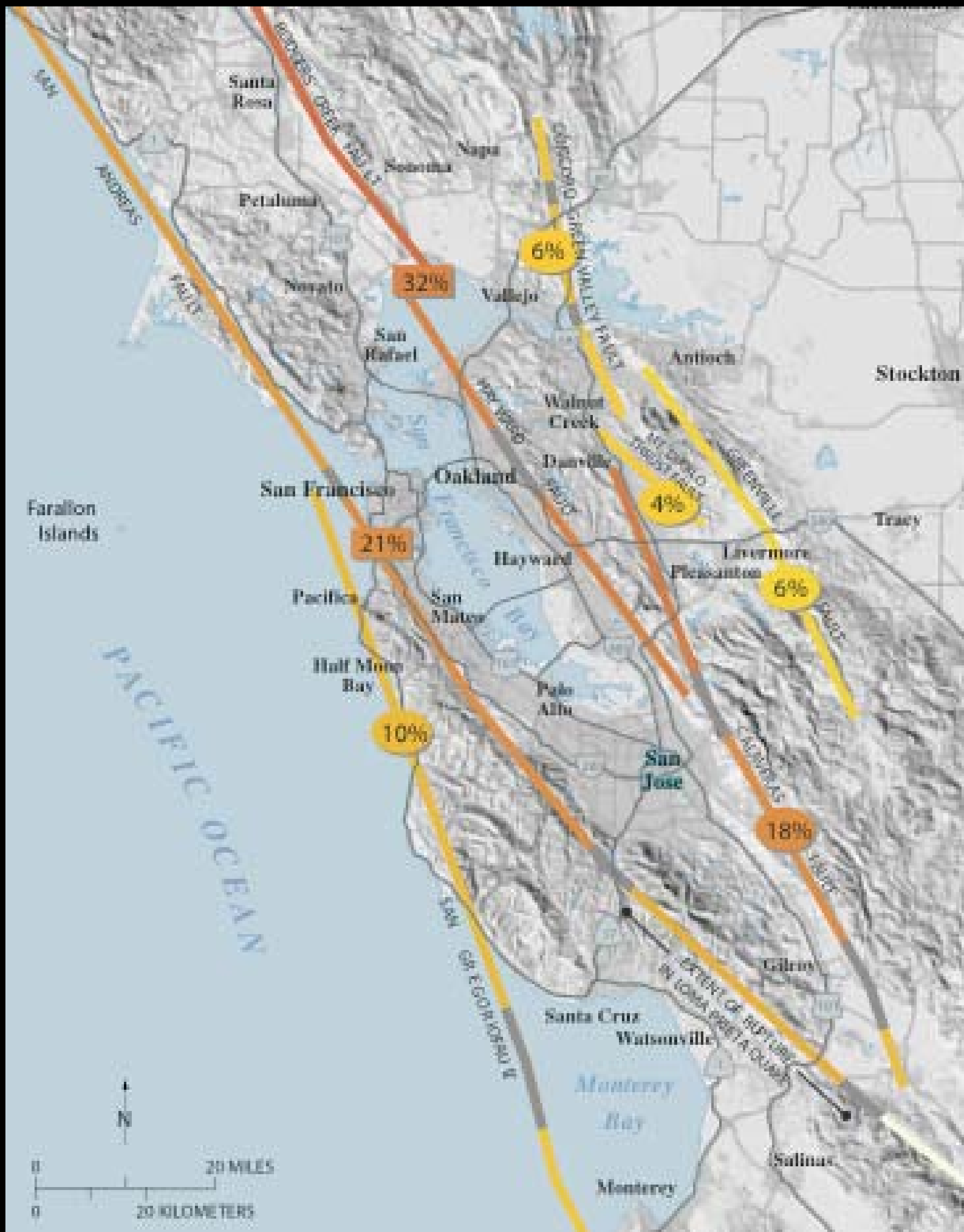
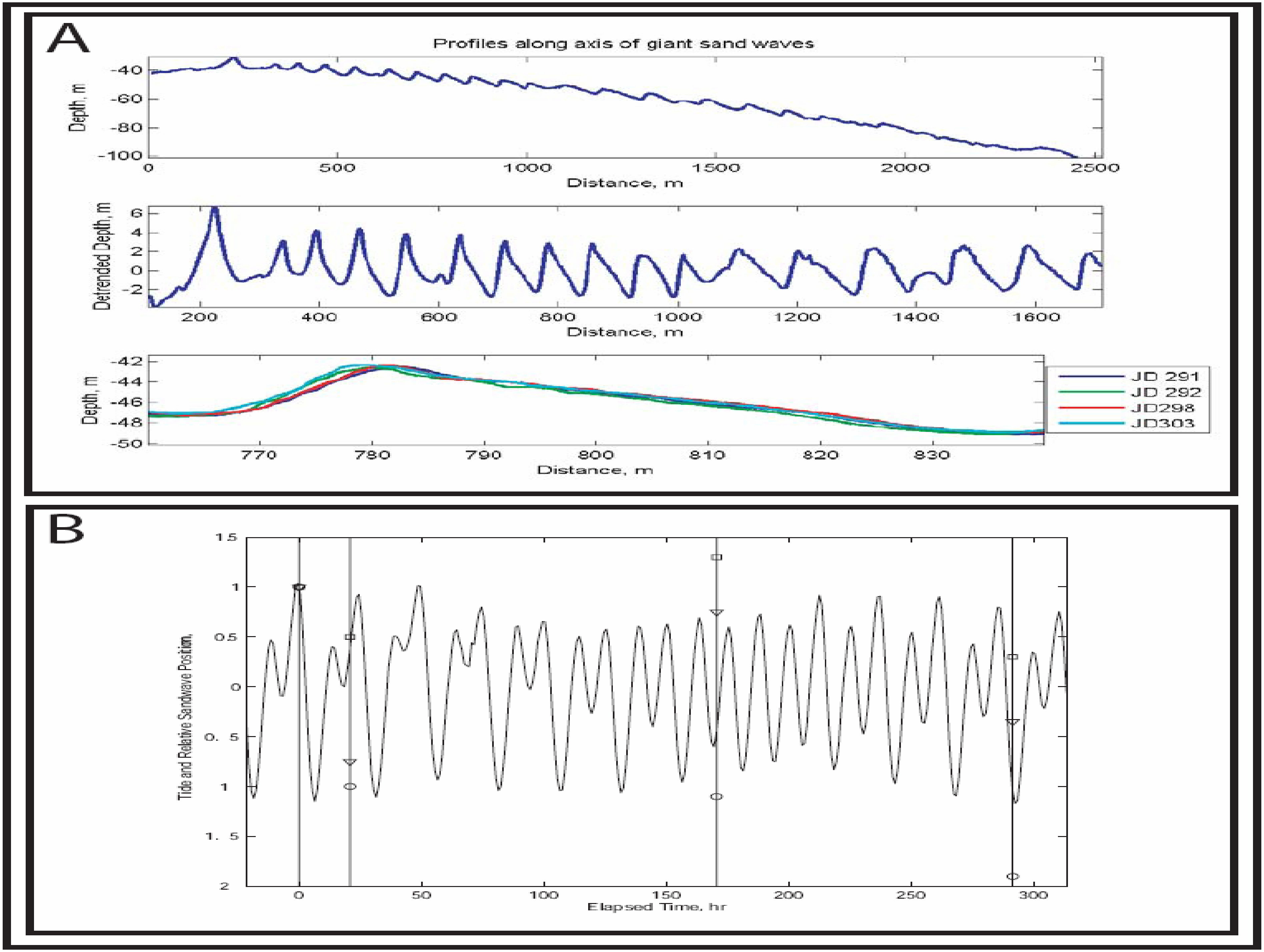


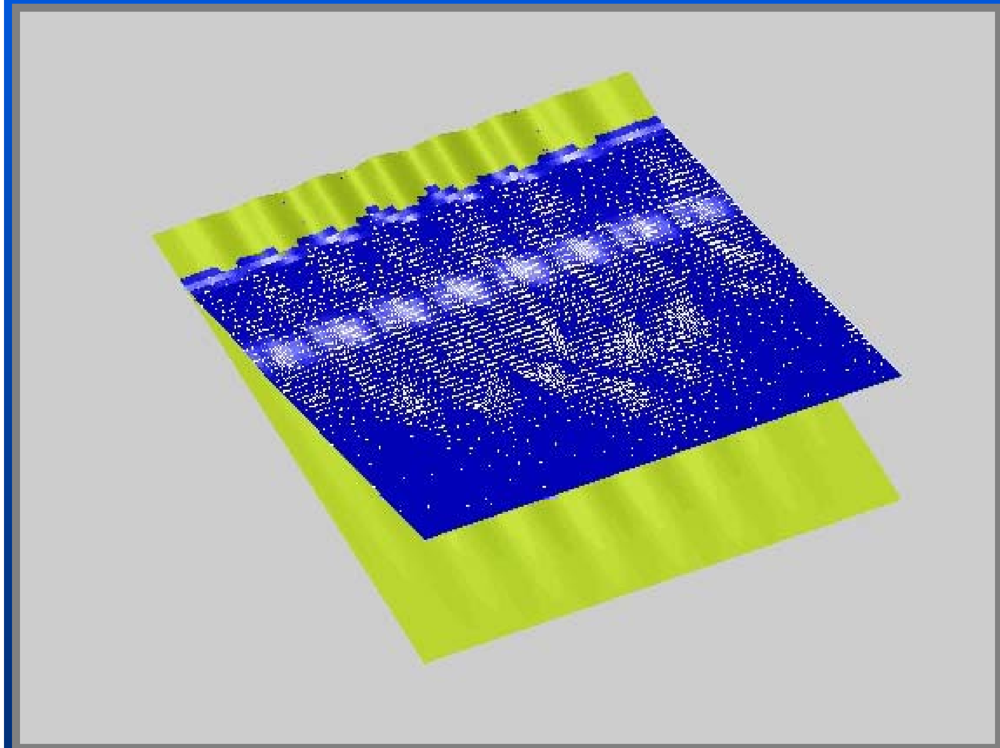
MAJOR FAULTS CONTRIBUTING TO 70% PROBABILITY OF A MAGITUDE 6.7+ EARTHQUAKE IN SAN FRANCISCO BAY AREA BEFORE 2030.

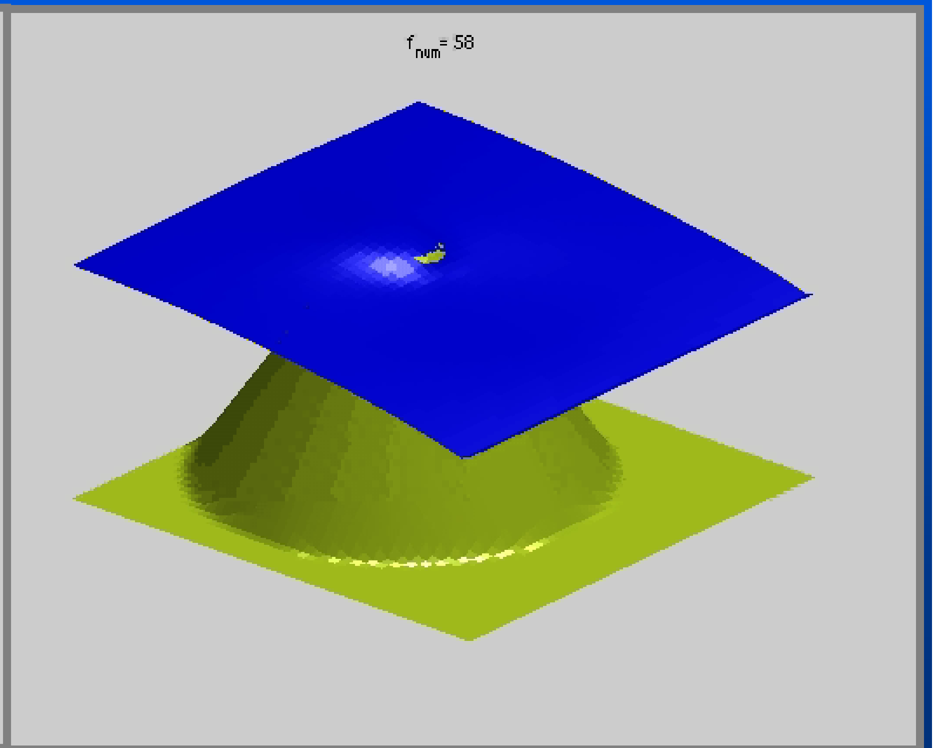

A
Profiles along axis of giant sand waves
Depth, m
-40
-60
-80
-100
0
500
1000
1500
2000
2500
Distance, m
Detrended Depth, m
6
4
2
0
-2
200
400
600
800
1000
1200
1400
1600
Distance, m
Depth, m
-42
-44
-46
-48
-50
770
780
790
800
810
820
830
Distance, m
JD 291
JD 292
JD298
JD303
B
Tide and Relative Sandwave Position,
1.5
1
0.5
0
0. 5
1
1. 5
2
0
50
100
150
200
250
300
Elapsed Time, hr

NearCoM Improvement for Multi-Scale Modeling

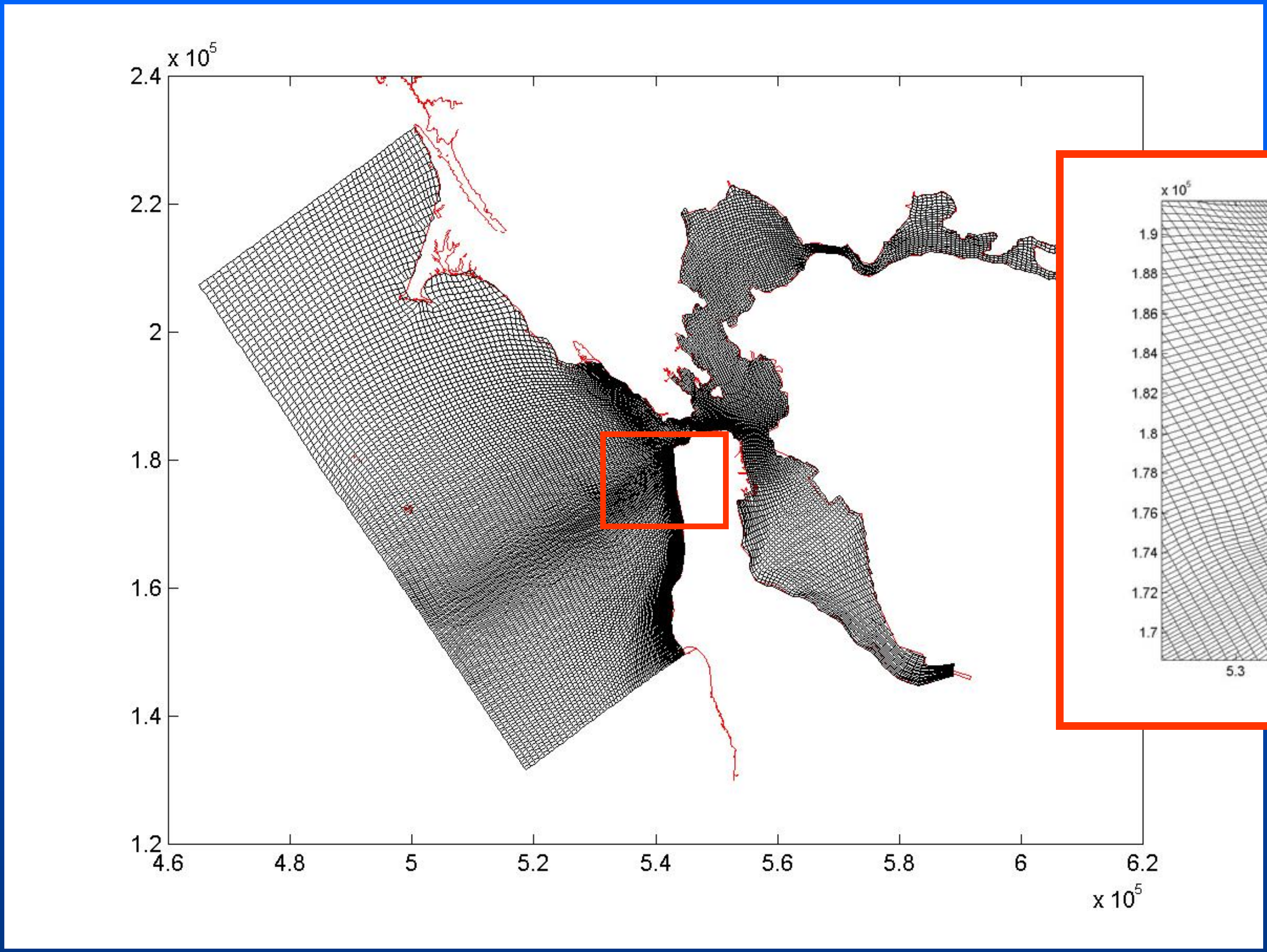
(F. Shi, Univ. Delaware)

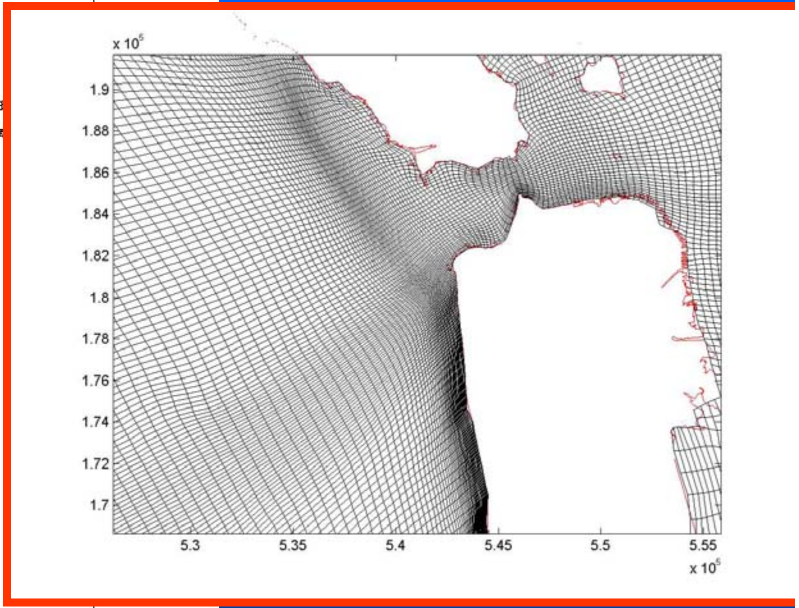
- Moving Shoreline Boundaries, Specified surface elevation, Domain extended
- beyond nearshore, and specified flux boundary conditions (for tidal forcing and river inflow)





NearCoM Grid for SF Application





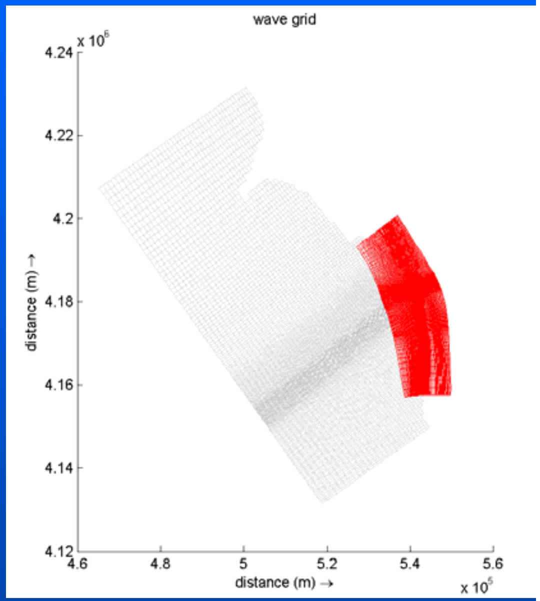
Maximum spacing 1320m
Minimum spacing 19m

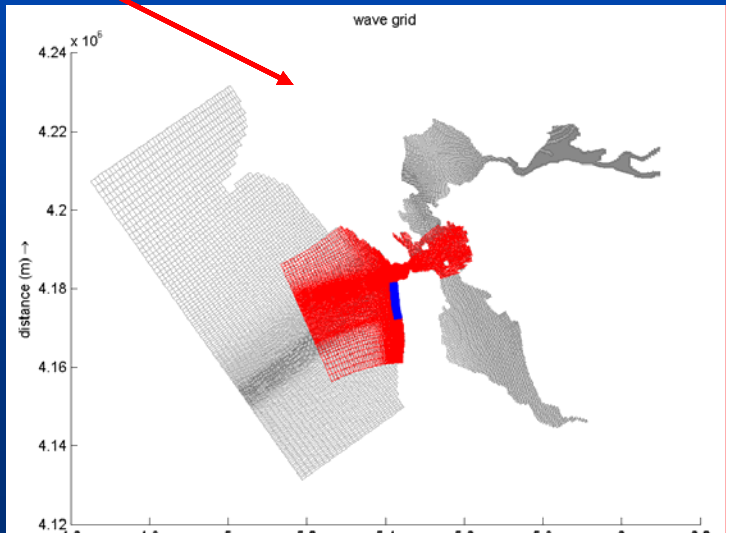
February 25th – 29th 2004 Storm

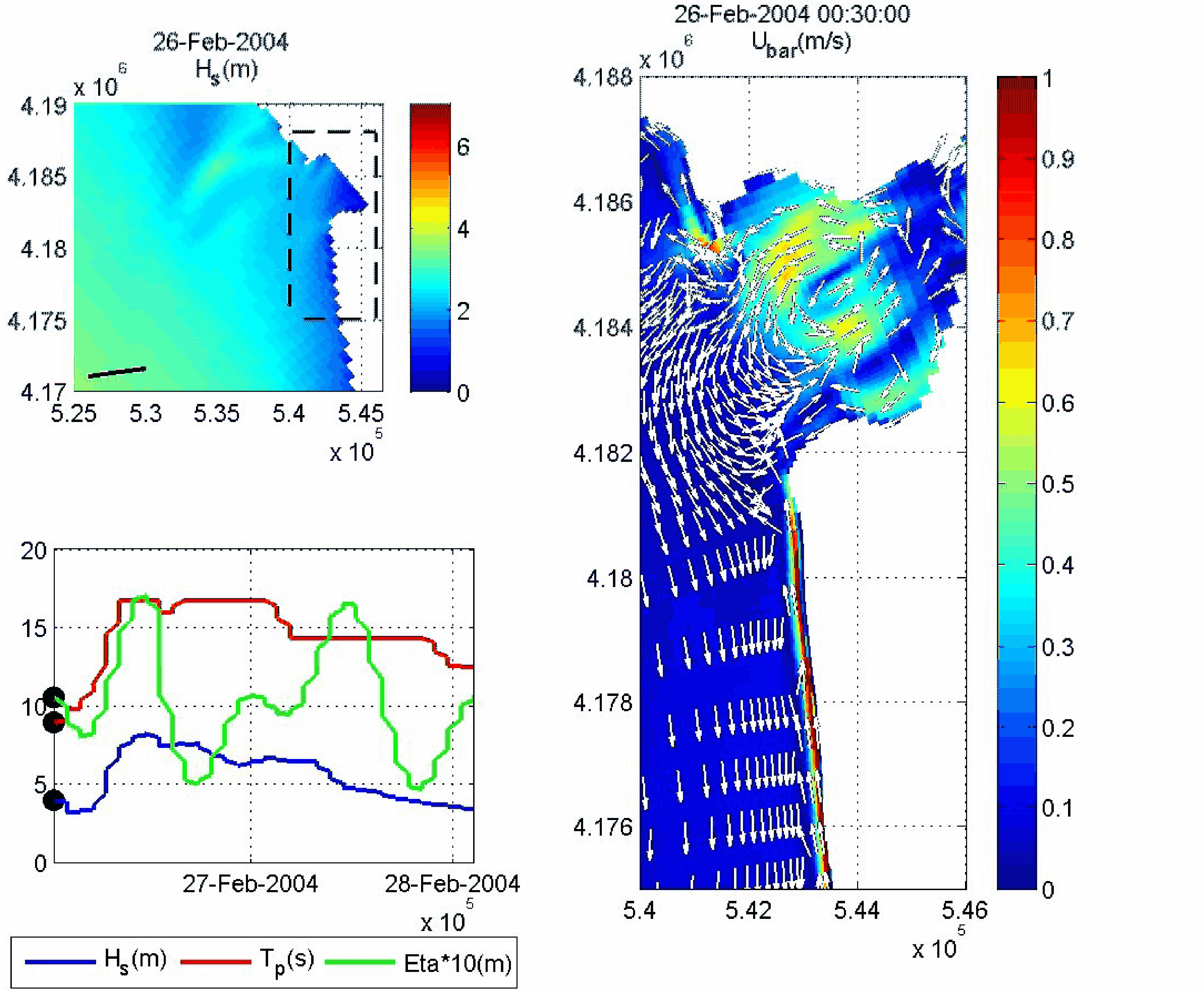
Storm peak conditions: *Due West waves, Hs ~ 8m, Tp ~ 16s*

Storm Modeling:

- DELFT3D
- Linked SWAN and FLOW
- Nested SWAN *(Overall and Intermediate Grids)*
- Nested FLOW *(Overall and Intermediate Grids)*
- Forced with H_s, T_p, θ_p, and wind

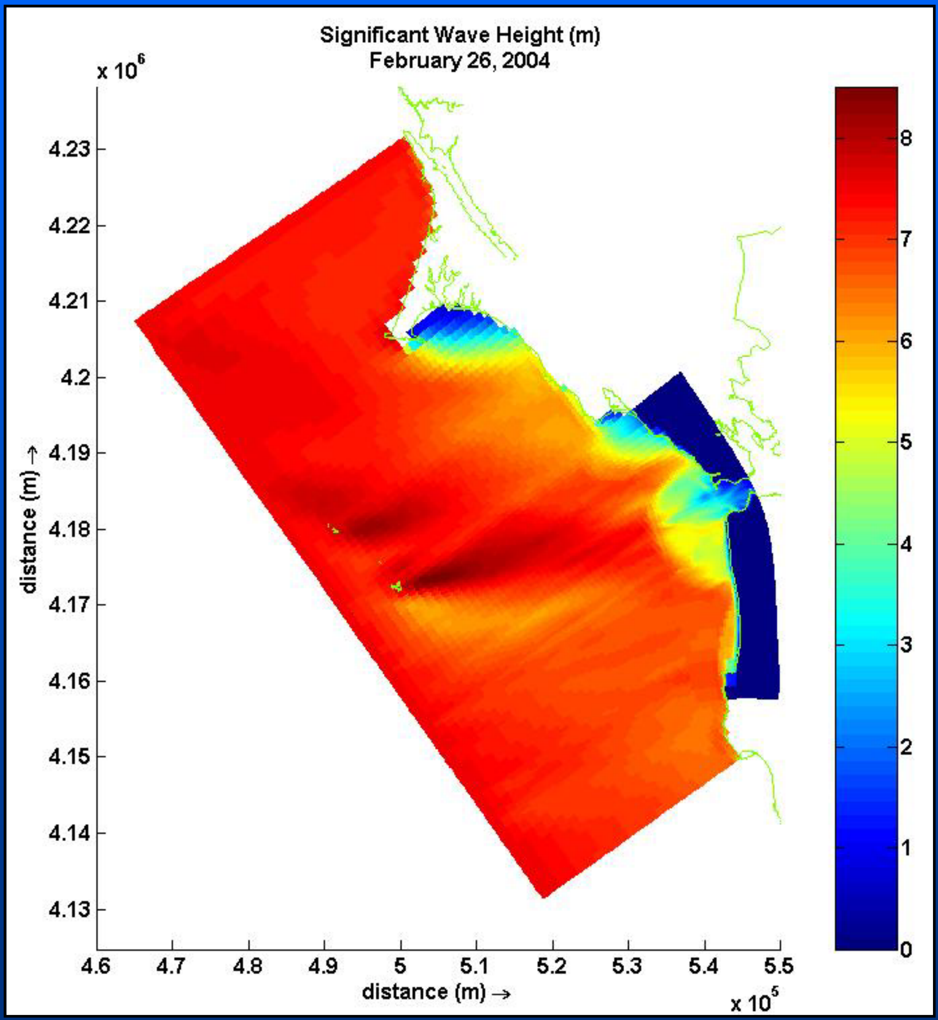




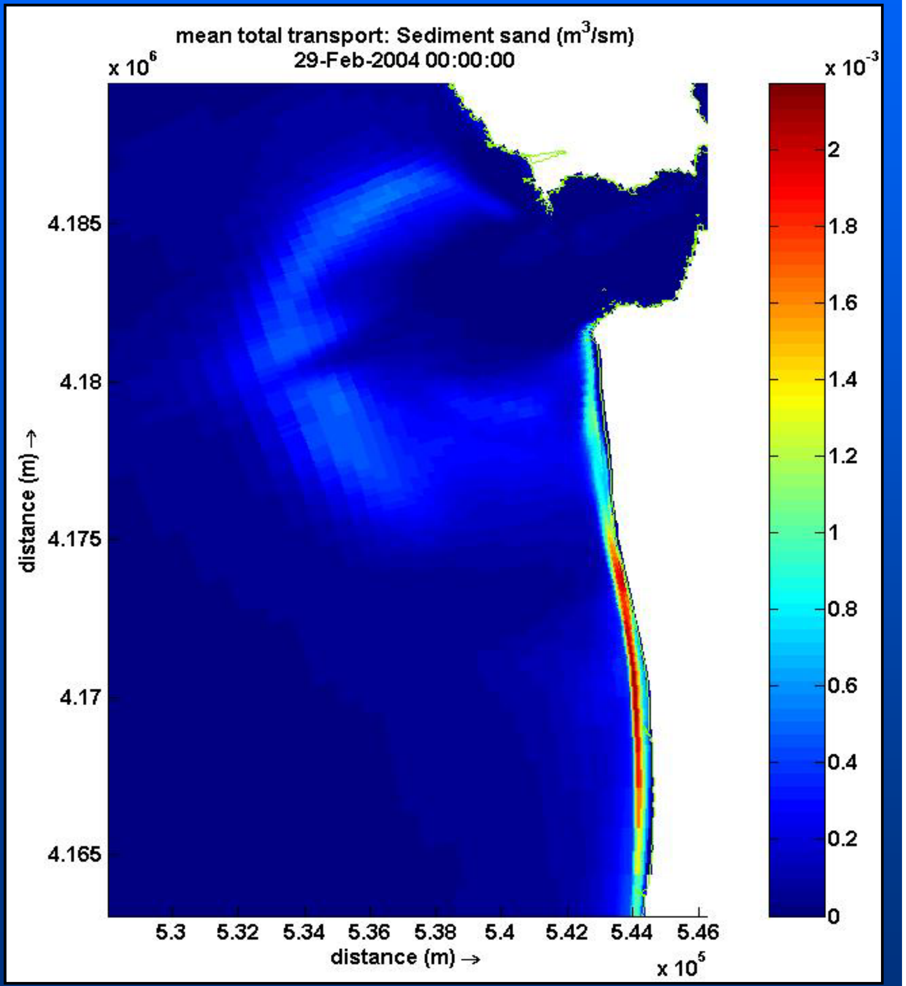

26-Feb-2004
H_s(m)
26-Feb-2004 00:30:00
U_{bar}(m/s)
27-Feb-2004
28-Feb-2004
H_s(m)
T_p(s)
Eta*10(m)

Modeling Extreme Events

Storm Wave Patterns



Storm Sediment Transport



NearCoM Improvement for Multi-Scale Modeling

1. Moving Shoreline Boundaries
2. Specified surface elevation and
   specified flux boundary conditions (tidal forcing and river inflow)
3. Semi-Implicit Numerical Schemes

<u>Previous Numerical Schemes</u>

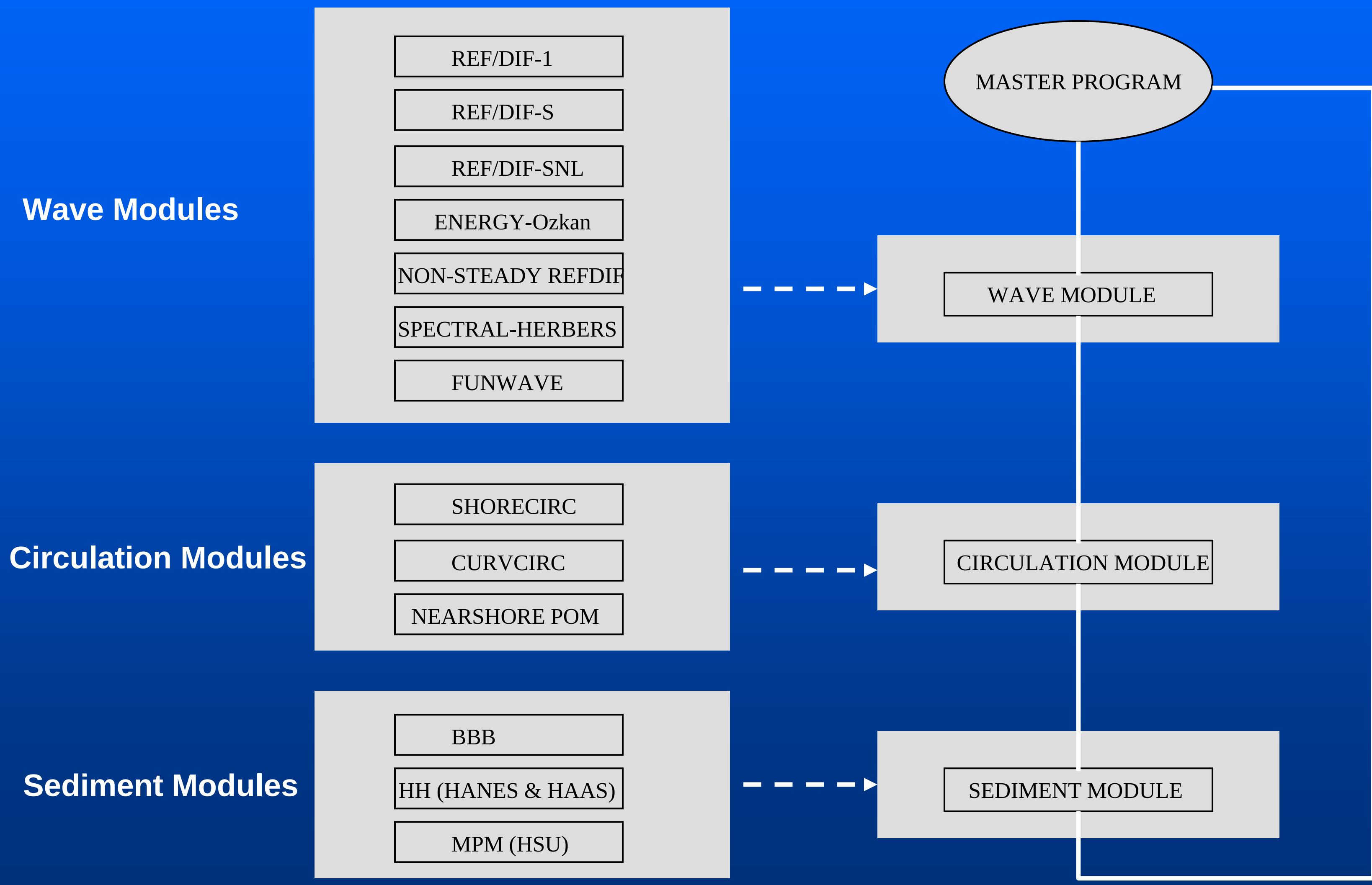
SHORECIRC 2.0:
Explicit schemes
CFL number <1
e.g., dx=10m, depth=10m, dt<1s

<u>New Numerical Schemes</u>

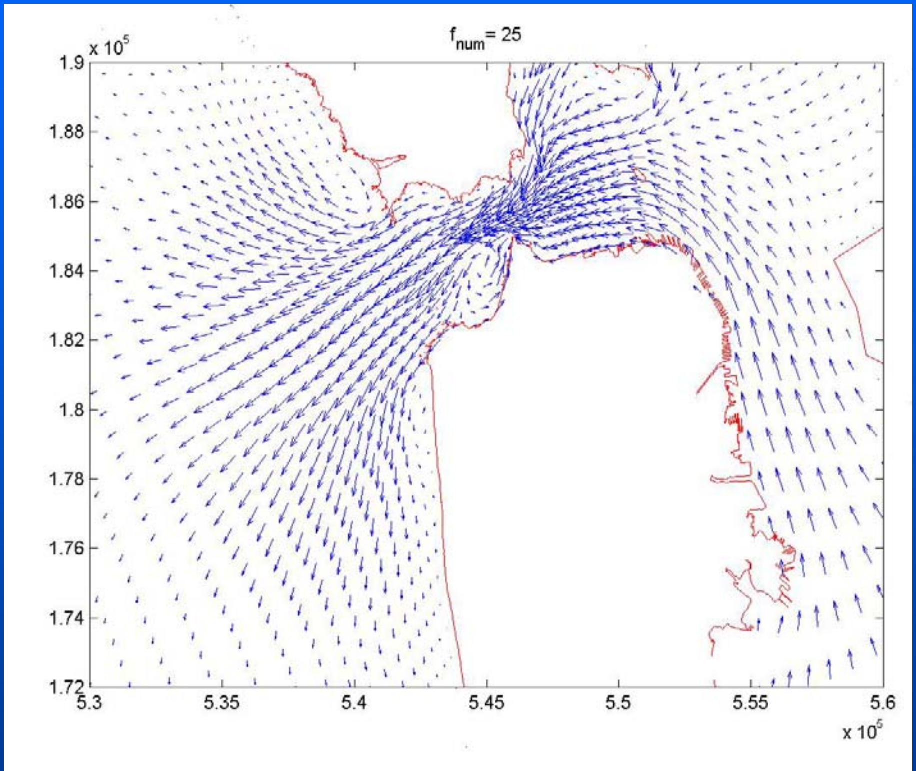
CFL-free: SHORECIRC = GRAVITY MODE +VORTICITY MODE

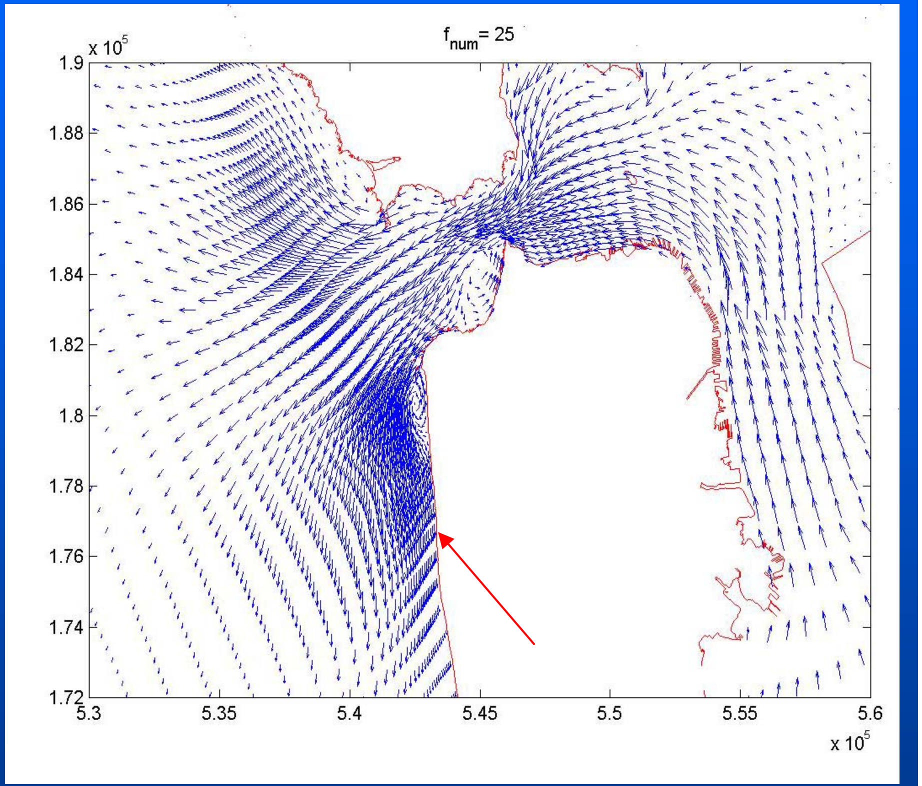
Implicit scheme **explicit scheme**

Nearshore Community Model (NearCoM)



NearCoM Results in SF Bight

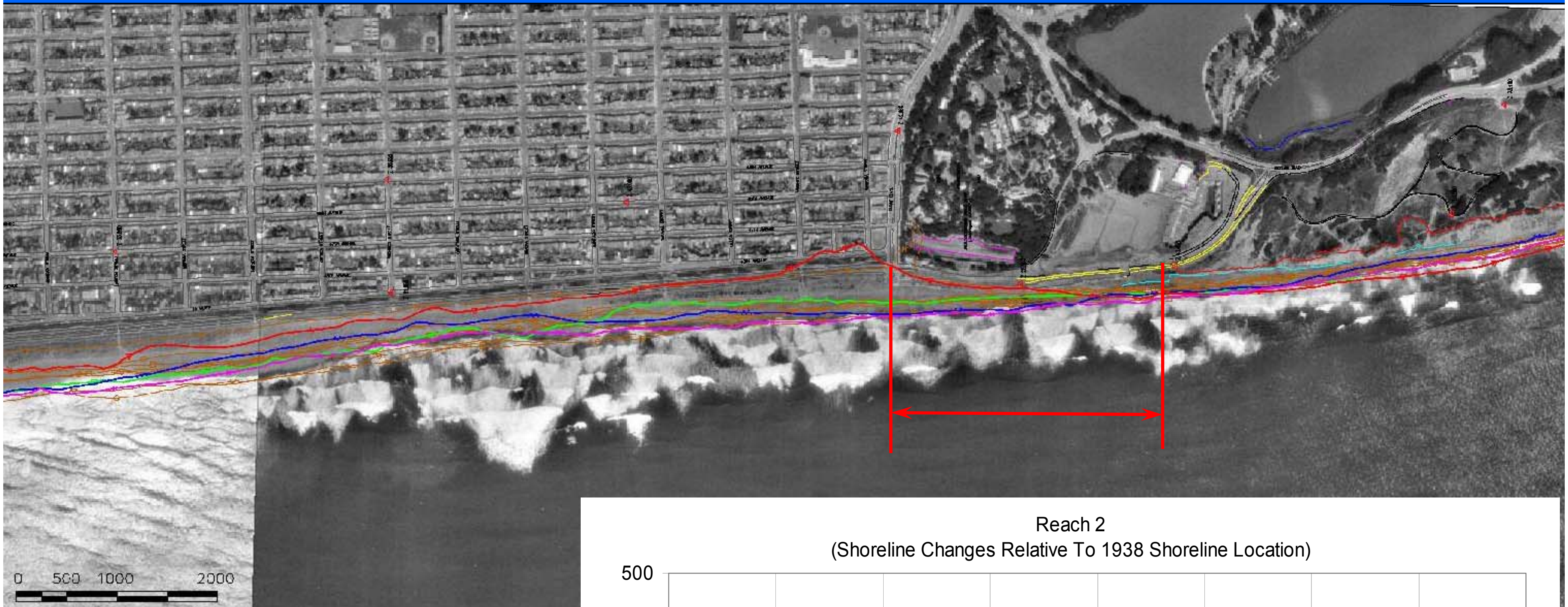




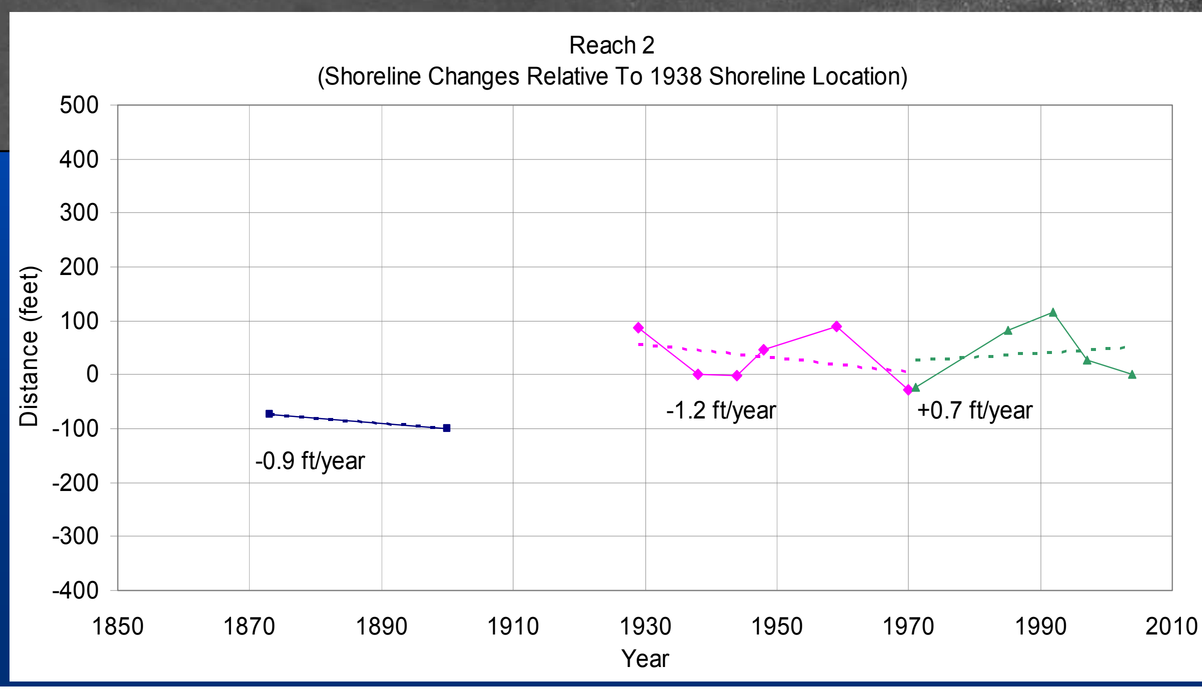
Coarse grid

Fine grid

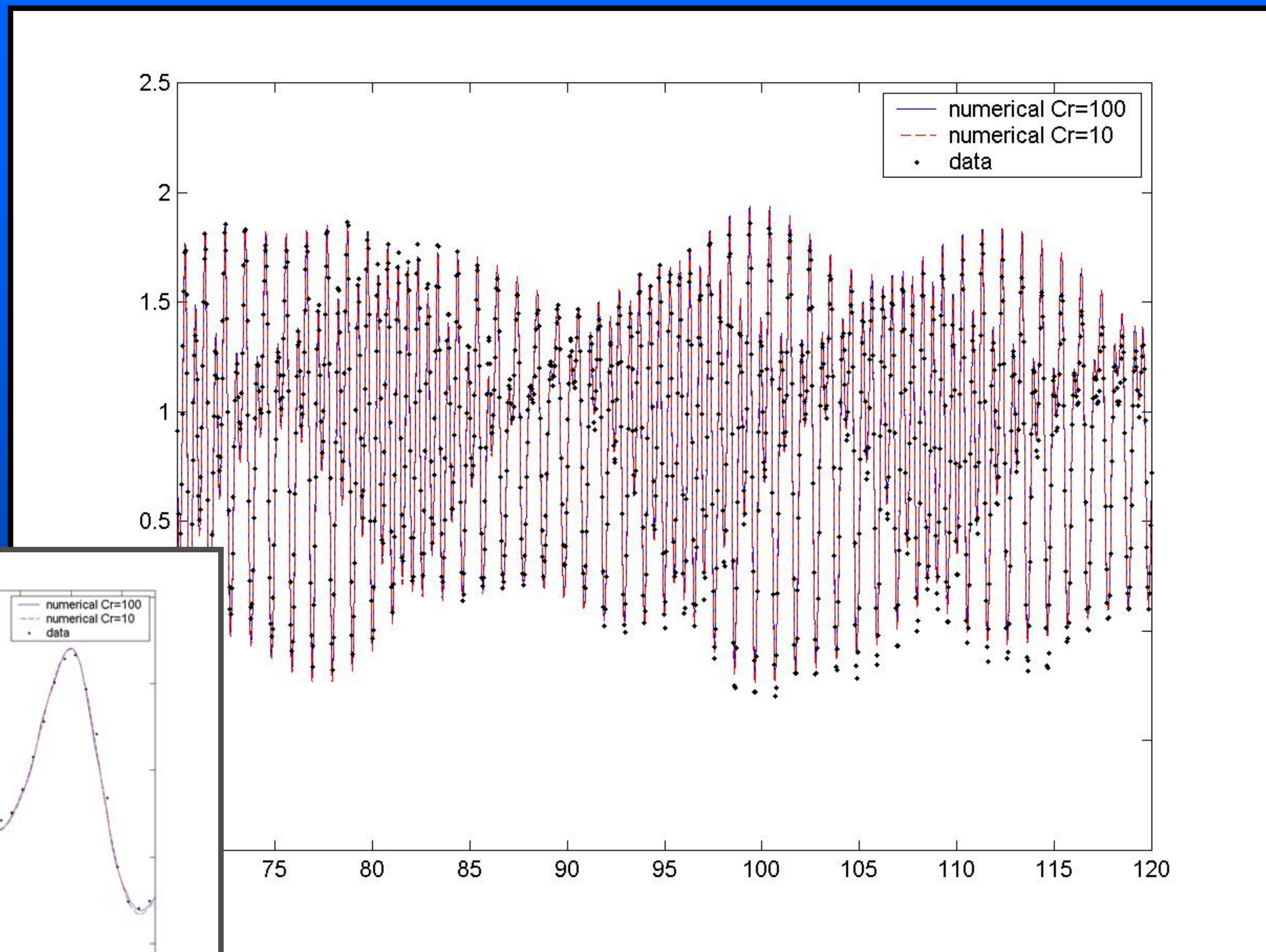
Shoreline Changes at Ocean Beach

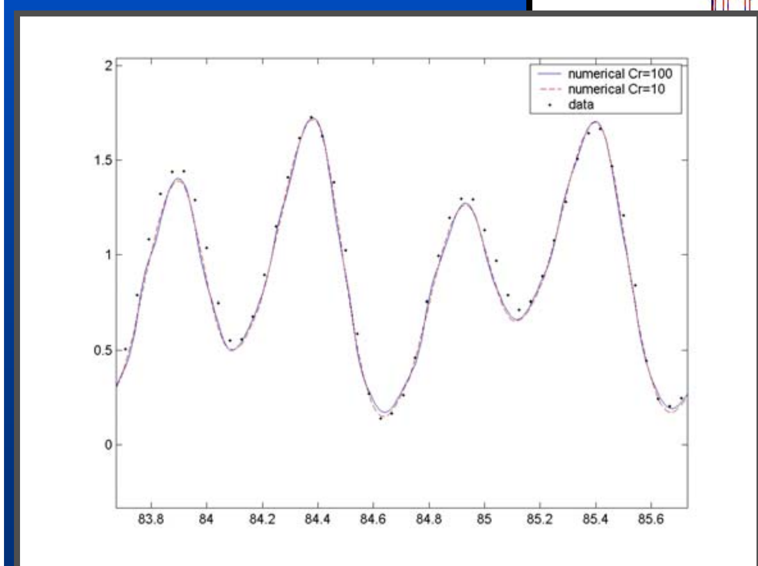


1873 shoreline
1938 shoreline
1985 shoreline
1992 shoreline



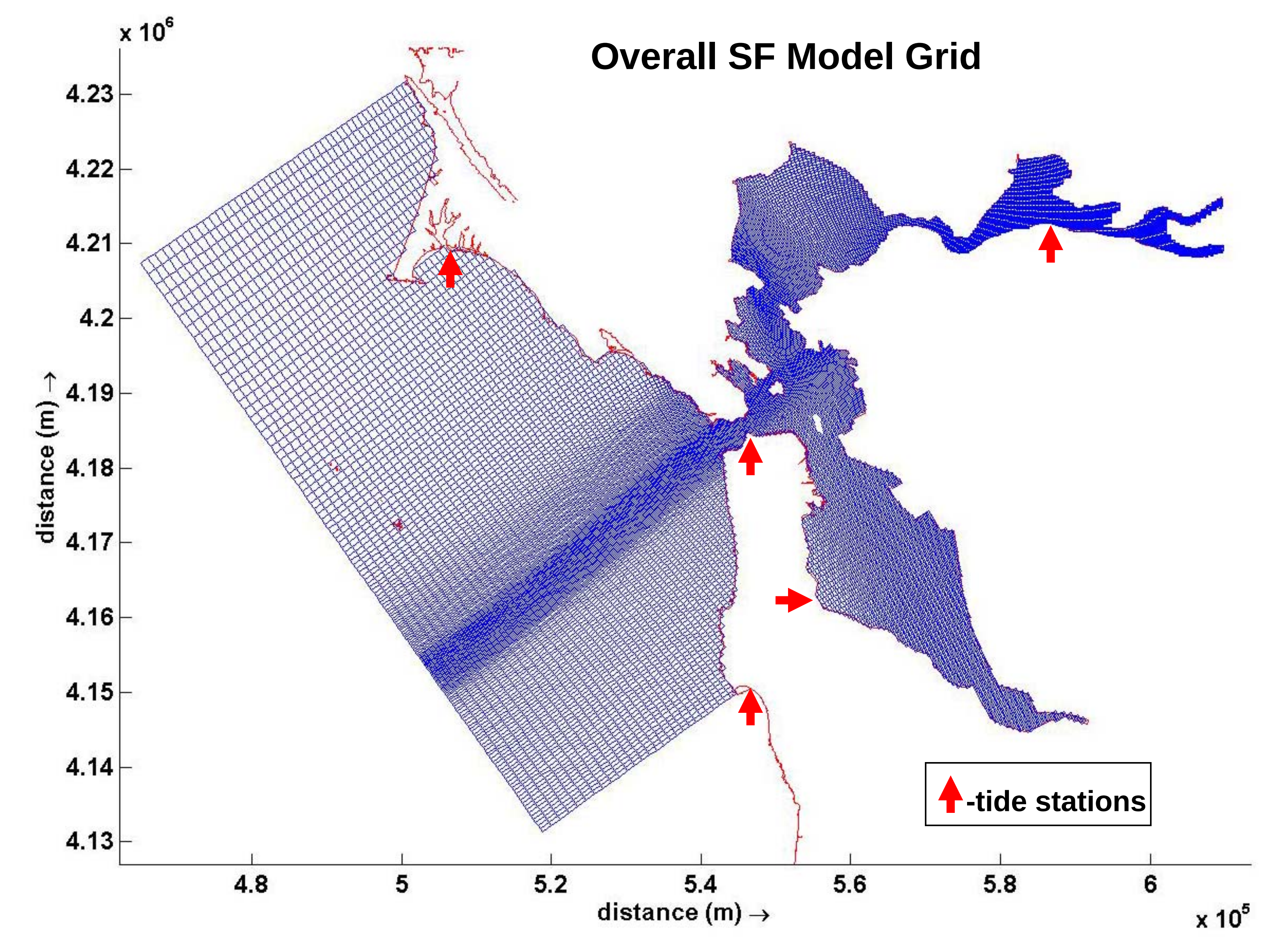
Model/Data Comparison for Tides (near Golden Gate

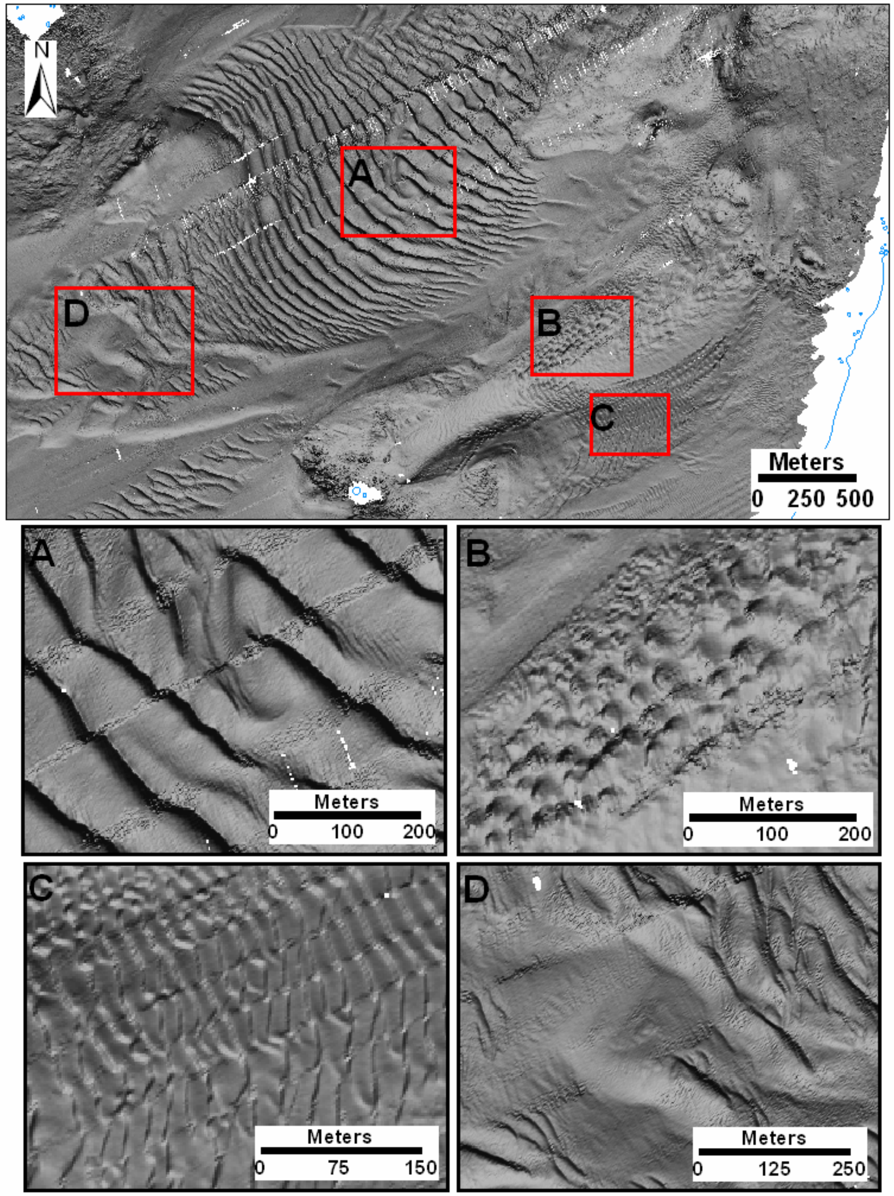




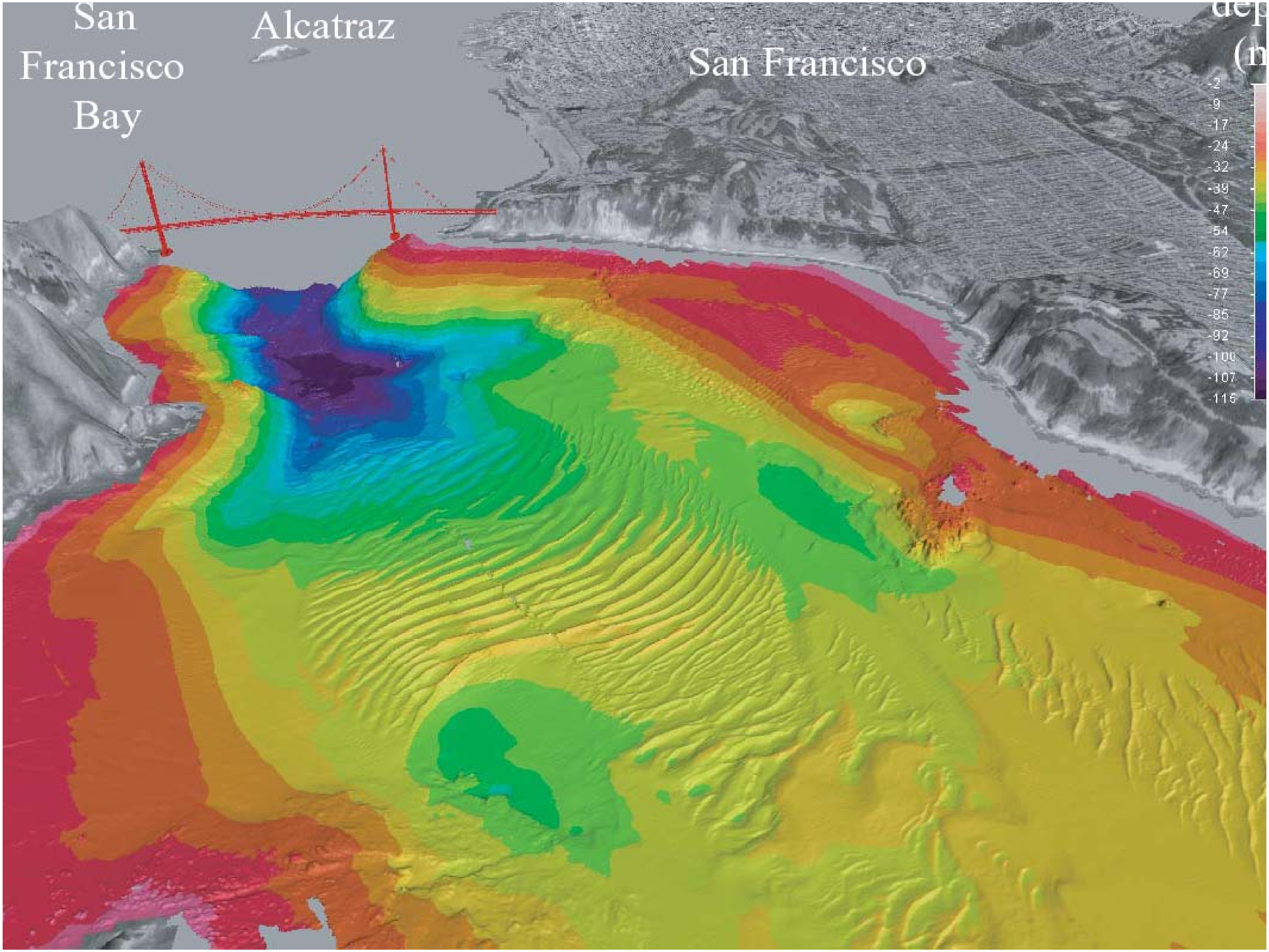
High Cr number does not change results

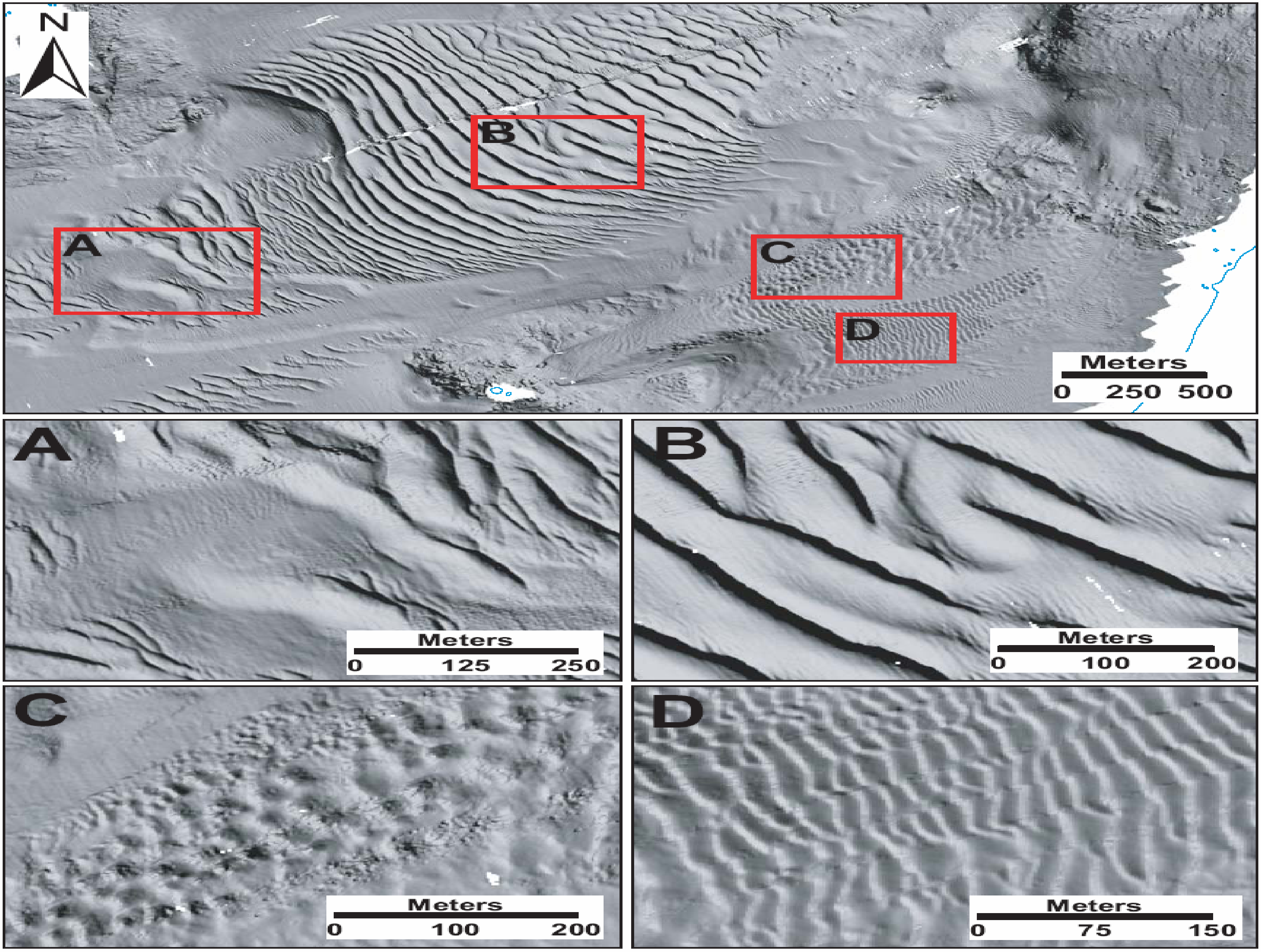
Numerical Modeling

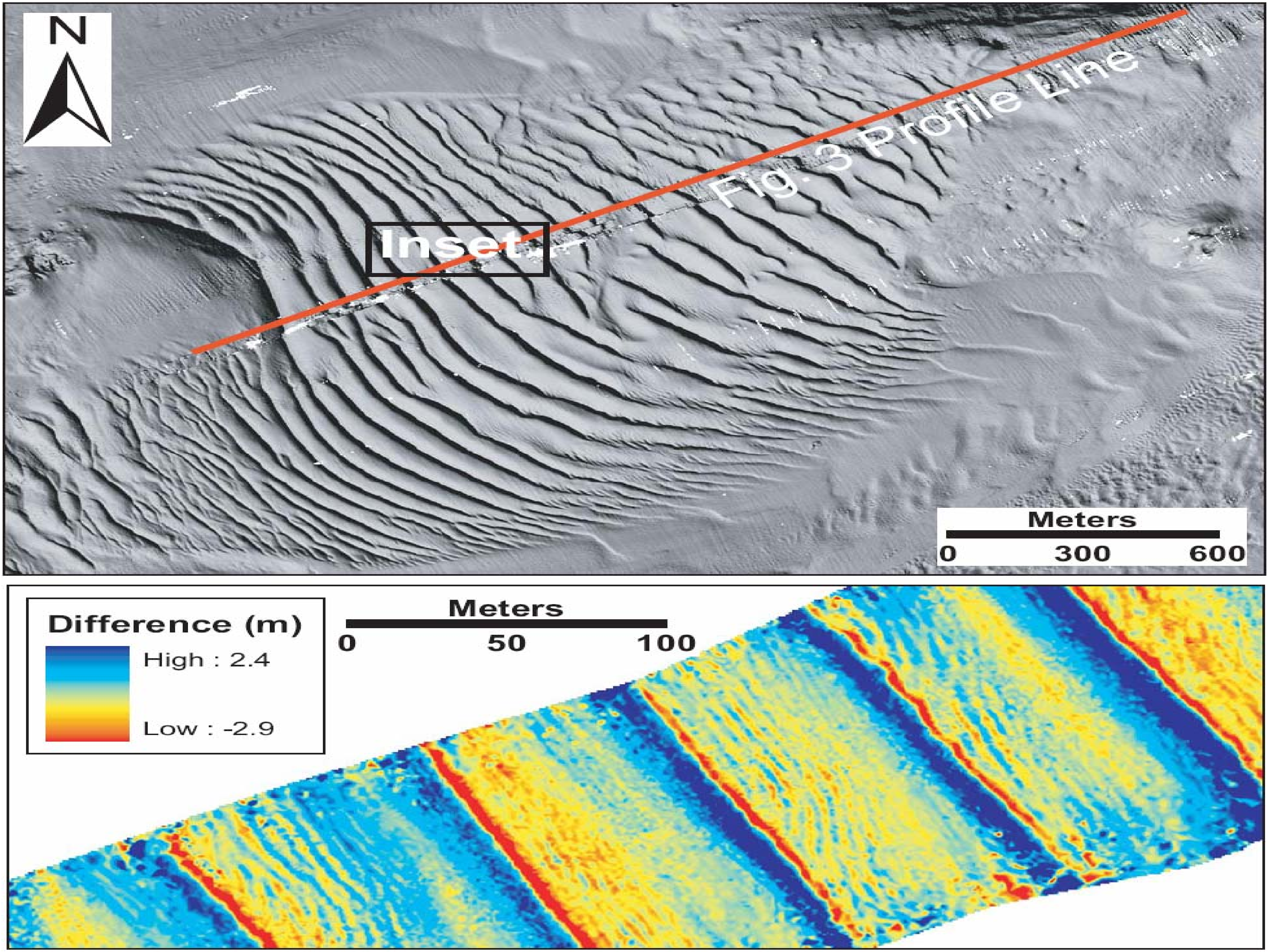




• Figure 5. Diversity of be… h superimposed ripples. B) 20-30 m scale linguoid-shaped sand waves. C) 15-20 m scale flood-dominated sand waves. C) irregular sand waves seaward of the main sand wave field.


San Francisco Bay
Alcatraz
San Francisco
-2
-9
-17
-24
-32
-39
-47
-54
-62
-69
-77
-85
-92
-100
-107
-115


N
A
B
C
D
Meters
0 250 500
A
Meters
0 125 250
B
Meters
0 100 200
C
Meters
0 100 200
D
Meters
0 75 150

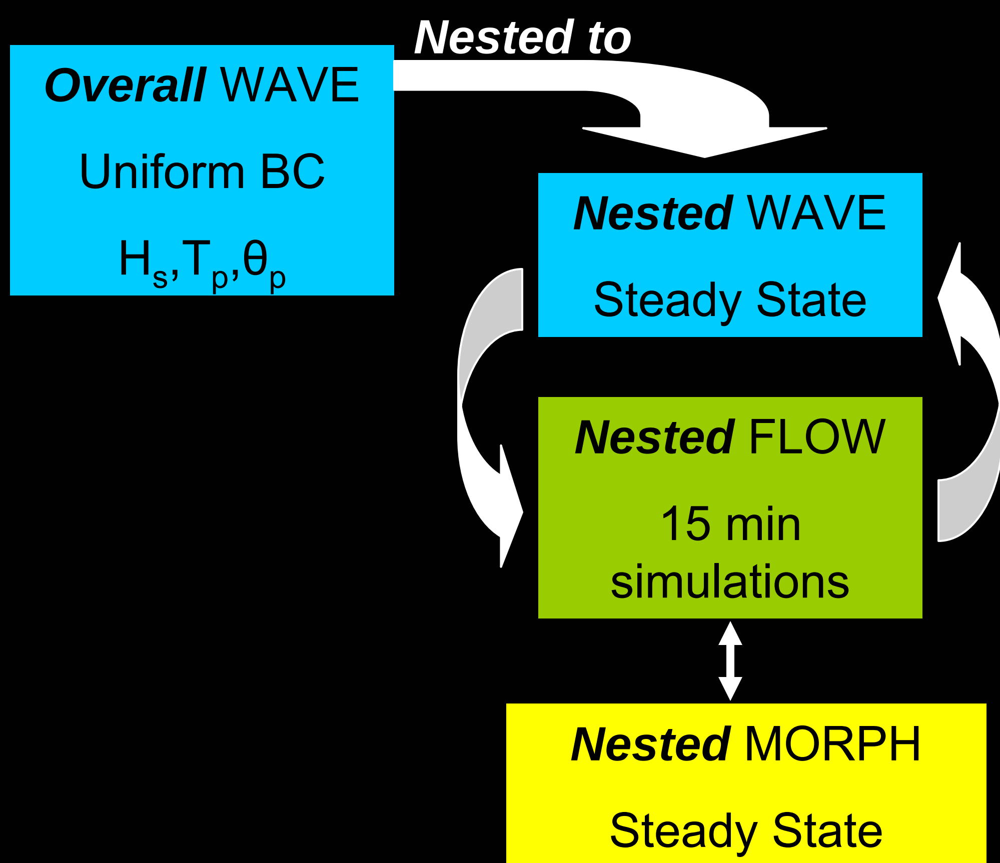

N
Fig. 3 Profile Line
Inset
Meters
0
300
600
Difference (m)
High : 2.4
Low : -2.9
Meters
0
50
100

DELFT3D: Linked and Nested Simulations Flow Chart:

1.

Produce: η(t) as input boundary condition for *Nested* FLOW

2.



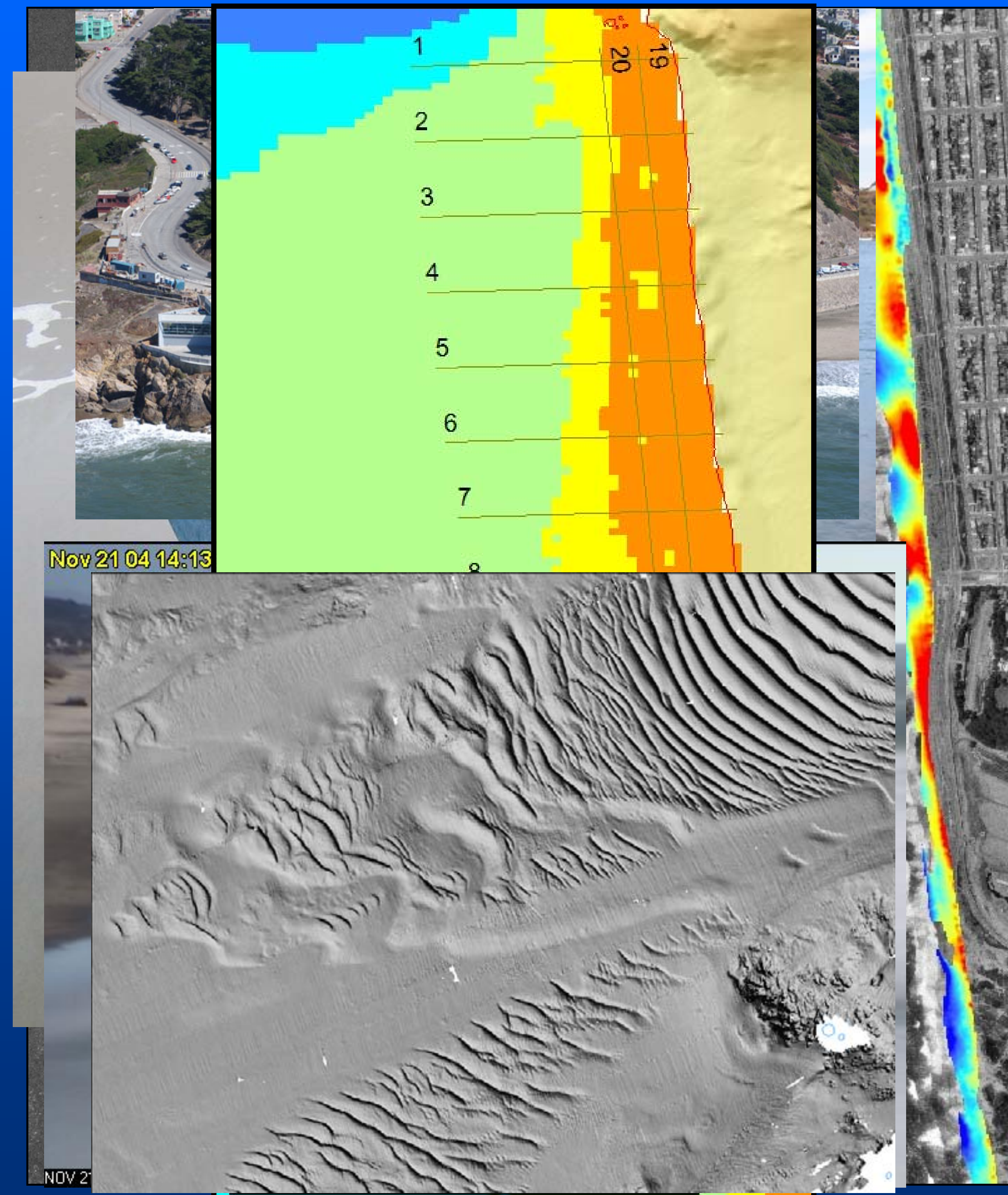
After each 15 minute FLOW simulation:

1. morphology is updated
2. waves are called

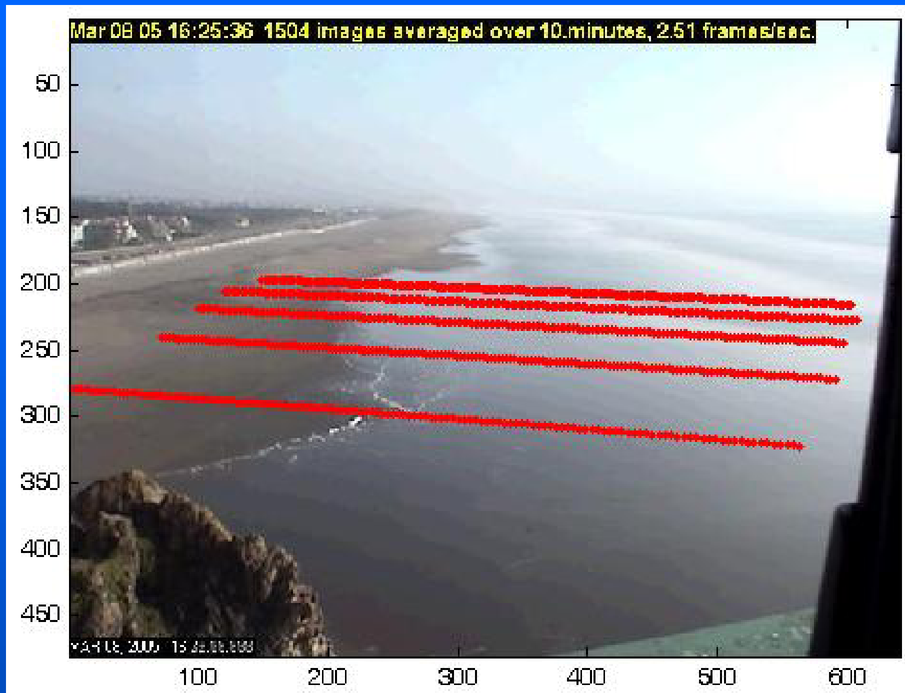
NOTE: Wave forcing is assumed to be constant for each 15 min FLOW simulation

Field Techniques and Examples of Observations

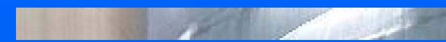
- All-terrain vehicle beach surveys
- Personal watercraft



Camera System: Li Erikson, Ann Gibbs, Patrick Barnard (EVS system)



for each transect



Stack images from each transect to generate 'time-stacks'

Increasing time

Run-up height
Swash period
Break point
Surf zone width

Original oblique image

Rectified image